An Assessment of Oil and Gas Water Cycle Reporting in California

Preliminary Evaluation of Data Collected Pursuant to California Senate Bill 1281, Phase I

An Emerging Topic Report prepared by the California Council on Science and Technology

CCST
CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

A nonpartisan, nonprofit organization established via the California State Legislature — making California's policies stronger with science since 1988

An Assessment of Oil and Gas Water Cycle Reporting in California:

A Preliminary Evaluation of Data Collected Pursuant to California Senate Bill 1281, Phase I

An Independent Review of Scientific and Technical Information

White Paper

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About CCST

The California Council on Science and Technology is a nonpartisan, nonprofit organization established via the California State Legislature in 1988. CCST responds to the Governor, the Legislature, and other State entities who request independent assessment of public policy issues affecting the State of California relating to science and technology. CCST engages leading experts in science and technology to advise state policymakers — ensuring that California policy is strengthened and informed by scientific knowledge, research, and innovation.

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Acronyms and Abbreviations

API	API number
CASRN	CAS number
CAS	Chemical Abstracts Service
CDPH	California Department of Public Health
CEC	Constituent of Emerging Concern
CVRWQCB	Central Valley Regional Water Quality Control Board
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
DWR	Department of Water Resources
IEX	Ionic Exchange
NASS	National Agricultural Statistics Service
SDI (SDIP)	Suitable for Domestic or Irrigation Purposes
SDWA	Safe Drinking Water Act
SCAQMD	South Coast Air Quality Management District
TDS	Total Dissolved Solids (ppm or mg/L)
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USGS	United States Geological Service

Summary

This white paper is the deliverable of Phase I of the California Council on Science and Technology's (CCST) study of the data collected by the Division of Oil, Gas, and Geothermal Resources (Division) in the Department of Conservation, pursuant to Senate Bill 1281 (SB 1281, Pavley, 2014). The overall purpose of this study, carried out in two phases, is to evaluate the utility of the SB 1281 dataset for answering important questions relating to water that is used, produced, stored, treated, reused and disposed of during oil and gas activities, and to suggest improvements where possible. As of the writing of this report, these data are available from the first quarter of 2015 to the second quarter of 2017; quarterly data summary reports are available for the same period.[1]

The goal of Phase I of the SB 1281 data study is to develop a series of questions responsive to the intent of SB 1281: to increase transparency about the impact of oil and gas activities on water resources in California. A subset of these questions will guide evaluation of the dataset in several ways during Phase II of the study. First, through direct appraisal of the SB 1281 data quality; completeness, accuracy, and accessibility of the data collected and stored by the Division will be explored. Second, by working toward answering several key questions that relate to water use, production, storage, treatment, and disposal in the oil and gas industry, the study team will test not only the fit of the dataset's variables for such a purpose, but also how well it can be used in conjunction with other available datasets.

The series of questions provided herein does not indicate a scope of work, but rather questions on a broad range of topics that such a dataset might be expected to address, either independently or in conjunction with other available datasets. The list of questions in Phase I is broad in scope and seeks to address the intent gof SB 1281. The range of questions will subsequently be narrowed considerably for analysis in Phase II through careful consideration of each question's specific nexus with the data and intent of SB 1281, and the study team's ability to productively address the issue with the current dataset, as well as to present novel data analyses that contribute to our understanding of these topics.

This white paper presents a primary study question and five secondary evaluation questions om order to guide the preliminary assessment of the utility of the SB 1281 dataset to a wide range of data end-users, from the general public to decision makers. Each of these broad questions has a series of associated operational questions, which are designed to have quantitative answers. Each operational question is assessed for its tractability, significance, relevance, and feasibility, defined herein.

1. Available at: http://www.conservation.ca.gov/dog/SB%201281/Pages/SB_1281DataAndReports.aspx

The primary study question is: *What is the utility of the SB 1281 dataset to answer important questions on water resources, public health, and the environment, and are there opportunities for improvement?*

The secondary evaluation questions, or key scientific questions that will provide use cases to test the SB 1281 dataset performance, follow two general themes: assessing the impact of oil and gas activities on the (1) quantity and (2) quality of various water resources, including recycled produced water.

Though Phase I is intended to present questions and leave the bulk of analysis and data appraisal for Phase II, early exploration of the dataset has already yielded some initial insights.

First, most of the data collected are related to water *quantity*—additional variables and details specifically about water quality would make the SB 1281 dataset more useful. As reported now, it does not contribute enough new data to answer fundamental questions pertaining to produced water quality, even though gaining an understanding of produced water quality is crucial to evaluating the potential of produced water reuse—and is therefore aligned with the intent of SB 1281. In some cases, the information needed has not been collected or reported systematically by any entity. The only water quality variable consistently reported is salinity, which by itself yields an incomplete picture of how safe water is for various applications. In other cases, better organization of data that are already reported would contribute greatly to our understanding of produced water quality. The SB 1281 dataset does address a significant unknown about produced water quality: salinity. While it is problematic to rely solely on salinity to inform discussions about appropriate quality of produced water for various applications, having more detail about salinity would be useful—for example, when considering the viability of various treatment options. Here is an instance where a finer categorization (more detailed than above or below a specific salinity level), or perhaps a modified request of operators (reporting measured salinity), would yield data that would be even more valuable than what is currently available, to a wide range of data users.

Second, as noted above for salinity data, more detailed categories in the reporting system would be useful. Though the suite of variables collected by the Division appeared to the authors at the outset to be sufficient to answer many essential questions posed here, a closer look at the categorization of some variables revealed the data to be limited. In some cases, the level of detail required to answer these questions may be achieved with clearer categorization. One example is a clearer delineation of various treatments used on produced water. Other examples are highlighted in this report, but a more comprehensive appraisal and specific suggestions for improvement will be included as part of Phase II.

Third, better organization and more standardized aggregation of data from multi-well sites may be useful. The convention of averaging quantities over multiple wells may confound the interpretation of some analyses. Many analyses proposed here would be performed at the level of an oilfield, rather than to the scale of a single well. As water is sometimes produced from multiple formations in a single oilfield, the most appropriate scales for analysis will be considered in Phase II for each question separately.

Even in instances where data reporting can be improved, there appears to be sufficient data to address some very important questions relating to both quantity and certain aspects of quality of produced water. Of course, if further exploration of the datasets reveals significant data gaps, the ability to answer questions to the expected extent will be diminished. In this case, suggestions would be made to improve reporting and fill such gaps. This discovery phase will be a key early component of Phase II of CCST's study.

The SB 1281 Report, both Phase I and II, should be regarded as an opportunity to develop a yardstick by which to measure the utility of the current SB 1281 dataset, with preliminary data analyses carried out in service of that goal. This report is an early stage in an iterative process of developing the correct datasets to answer the most policy-relevant questions about the oil and gas water cycle.

Introduction

The California Council on Science and Technology (CCST) is called upon to provide credible, relevant, and independent information and analysis to inform policy decisions related to science and technology issues.

This white paper is the deliverable of the first phase of a study CCST has undertaken to evaluate the utility of the SB 1281 dataset at the request of the Division of Oil, Gas, and Geothermal Resources (Division). This document has been researched and written by principal researchers and select CCST staff under the guidance of a steering committee with an appropriate range of expertise, a balance of perspectives, and no conflicts of interest.[2]

CCST strives to produce documents through a transparent process that ensures the final product is responsive to the questions of the sponsor, while maintaining full scientific independence. This transparency is achieved by engaging the sponsor in dialogue about the nature of their needed information and informing the sponsoring agency of the study progress.

Terms used in this document

For the purposes of this Phase I white paper and for the Phase II report, the term "produced water" is used to encompass all non-hydrocarbon liquid streams emerging from an oil and gas well.[3] When necessary to the discussion, there will be reference to flowback or wastewater specifically, and it will be defined it in that context. The term "environment" is used in a broad sense to include wild ecosystems, agricultural ecosystems, geology and seismicity, quantity and quality of water resources, and the atmosphere. The term "disposition" is used here as the Division uses it, which is to say the method by which produced water is disposed from a production well, including to sump, transfer to other parties, reuse in operations or elsewhere, etc. Finally, three question types are presented in this white paper: (1) a primary study question, or the driving question of the CCST SB 1281 Data project; (2) secondary evaluation questions, or broad subject-matter questions a dataset such as the SB 1281 dataset might be expected to address; and (3) operational questions, or focused questions that could be used to exercise the SB 1281 dataset in order to evaluate its utility for answering the broader secondary evaluation questions.

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2. In cases where a conflict is deemed unavoidable, CCST would promptly and publicly disclose it. No conflicts of interest were identified in the preparation of this paper.

3. According to PRC § 3159, "Flowback fluid" refers to the fluid recovered from a treated well before the commencement of oil and gas production from that well following a well stimulation treatment; which narrows the definition of "produced water" to be all wastewater that emerges from the well after production begin. Notwithstanding the technical definitions, the term "produced water" is frequently used to refer to any produced liquid apart from the recovered petroleum products, and is how we use it in this report.

Background

History of Oil Production in California[4]

Oil and gas production remains a major California industry. California hydrocarbon reservoirs have some of the highest concentrations of oil in the world. Commercial production started in the middle of the 19th century from hand-dug pits and shallow wells. In 1929, at the peak of oil development in the Los Angeles Basin, California accounted for more than 22% of total world oil production. California's oil production reached an all-time high of almost 400 million barrels in 1985 and has declined since then. In 2017, California produced more than 170 million barrels of oil and was the fourth highest-producing state, with about 5% of U.S. production (Figure 1). In 1960, almost as much oil was produced in California as was consumed, but by 2012 Californians produced only 32% of the oil they used (198 million barrels produced in the state out of a total of about 621 million barrels consumed). Over the years, as California fields have matured, operators have used water flooding, gas injection, thermal recovery, hydraulic fracturing, and other techniques to enhance oil and gas production.

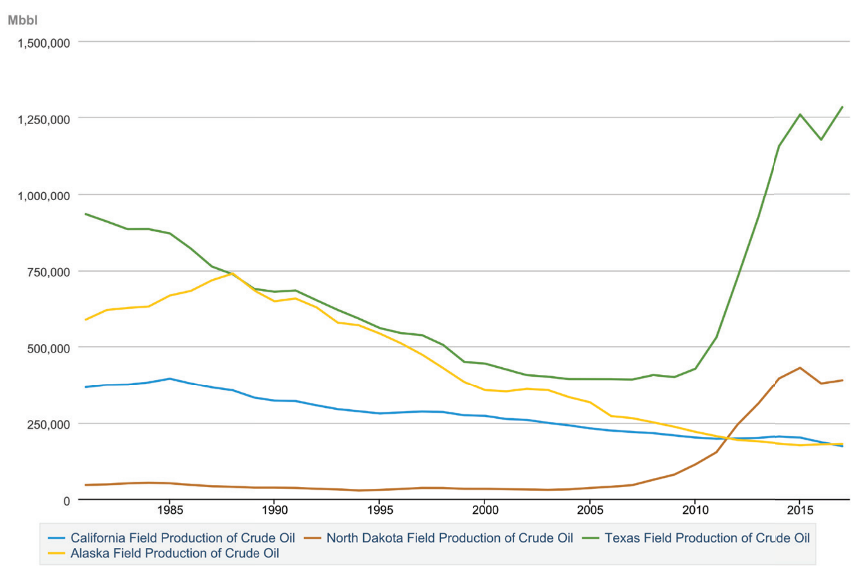

Figure 1. Crude oil production by the four top oil-producing states. California was the fourth most productive state for crude oil in 2017, after Texas, North Dakota, and Alaska. Units in million barrels of oil (Mbbl). Source: Reproduced from US EIA 2018a

4. Text modified and updated from Box 1 in CCST and LBNL, 2018.

California's oil and gas production is distributed throughout the state, but is concentrated in the southern portion of the state, principally the San Joaquin Basin and, to a lesser extent, the Los Angeles Basin (Figure 2), with a small amount of production in areas as far north as Butte County. In April 2018, California had over 80,000 active oil and gas wells in 509 fields (Division, 2018). The state produces a modest amount of natural gas, mainly as a co-product of oil production, and known as "associated" gas production. Though non-nuclear renewables have recently been gaining ground in California's portfolio of energy-producing sectors, oil still makes up the largest portion. Oil production accounted for 49% of all energy California produced in 2015, followed by non-nuclear renewable energy (31%) and natural gas (11%) (US EIA 2018b).

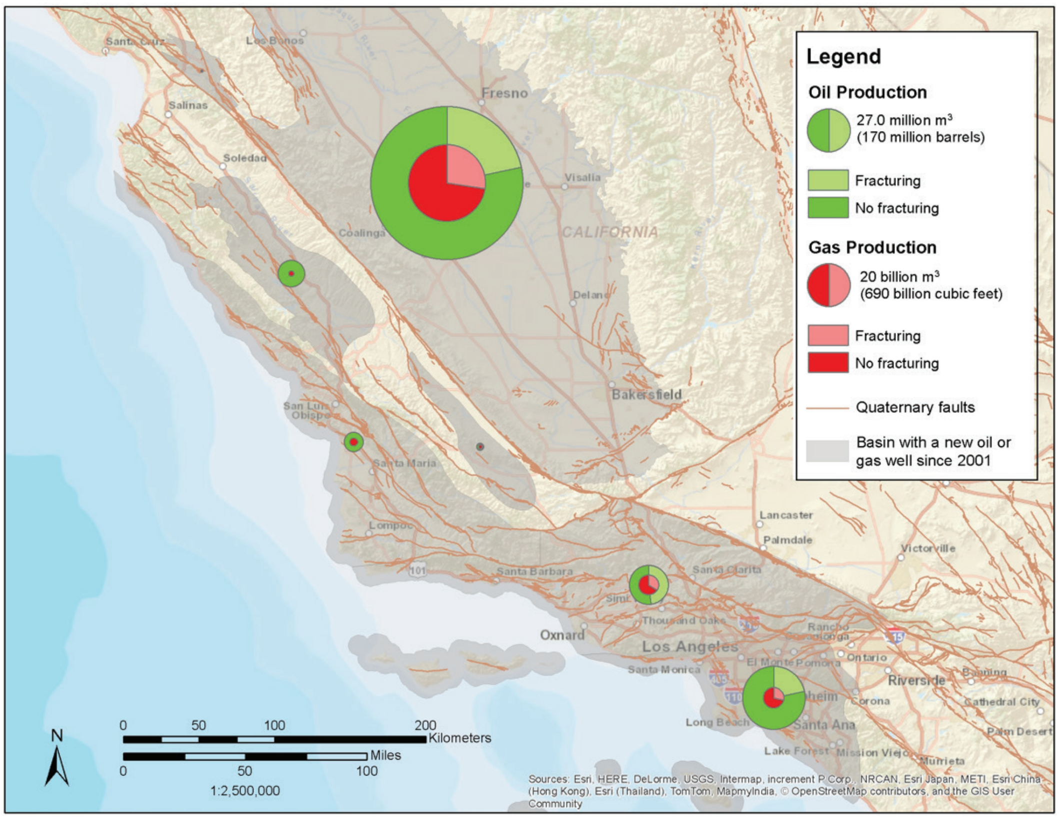

Figure 2. Production in the principal oil-producing basins in California from Jan 2002-May 2014. Source: Reproduced from SB4 Summary Report (CCST and LBNL, 2015).

Overview of SB 1281, Pavley. Oil and gas production: water use, reporting.

Over the past several decades, as production technologies have advanced and methods to capture more oil and gas from aging oil fields have improved, the use, production, treatment, reuse, and disposition of water as part of all oil and gas activities—not only hydraulic fracturing and well stimulation—have raised concerns for California decision makers. Water requirements throughout the exploration, development, and production stages of oil and gas operations have important implications for water management and energy production in the drought-prone state of California. Further, methods used to safely handle, dispose of, and reuse produced water of varying characteristics that may present human health and environmental risks are critical to adequately protect human populations, ecological communities, and environmental media surrounding the operations and increasingly throughout the State of California.

In 2013, California passed Senate Bill 4 (Pavley), which required the Division of Oil, Gas, and Geothermal Resources (the Division) in the Department of Conservation to, among other things, require full disclosure of the source, volumes, and specific composition and disposition of all chemicals used in well stimulation treatments (hydraulic fracturing, matrix acidizing, and acid fracturing) to the State Oil and Gas Supervisor. With SB 4, the Legislature declared that "protecting the state's groundwater for beneficial use, particularly sources and potential sources of drinking water, is of paramount concern (CALI, 2013)." This law was followed in 2014 by Senate Bill 1281 (Pavley), which added §3226.3 and amended §3227 of California Public Resources Code (PRC §§3226.3 and 3227), a data collection mandate to enhance existing water reporting requirements. This legislation was intended to address concerns about the oil and gas industry's impact on existing surface and groundwater by providing "public transparency and accurate recordkeeping" of the water used in oil and gas activities, as well as promoting the treatment and safe reuse of water in oil and gas fields and activities.[5] This intent was expressed as expanded requirements to document the sources of water used for and produced by oil and gas operations, and their ultimate specific uses, with explicit attention to untreated, low-salinity[6] produced water, the onsite storage of water, and identification of the various combinations of treatment techniques applied to any of these volumes of water.

As stated, the author's intention in crafting SB 1281 was to improve transparency of the use of water in the oil and gas industry and to promote the treatment and reuse of produced water in the oil field—treating it as a source of water instead of merely a waste stream. We take this intent to include information that could be used by the public, decision makers, and other stakeholders to inform improved stewardship of a crucial State resource, including: (1) how much water is required for the development and production of oil and gas; (2) how much of the water for oil and gas development comes from sources of water available for other uses (e.g., drinking, irrigation, etc.); and (3) how the storage, disposition, and uses of produced water might impact the quality (and therefore quantity) of other water resources suitable for purposes beyond the oilfield. As the bill language requires the Division to collect information about treatment and other intended reuse

5. According to the author's office. Senator Pavley, California Legislature, 2014.

6. Defined as 10,000 mg/L total dissolved solids.

options, we also understand the scope of questions that could be posed would include some discussion of water quality appropriate for various uses, to examine what barriers might exist to using produced water as a resource beyond the oilfield.

Given this understanding of the intent of SB 1281, there are several aspects of oil and gas operations that statute does not require the Division to collect that may be considered relevant. Specifically, the law as written leaves out important topics related to wastewater disposition and its associated consequences. For instance, chemicals used in oil and gas operations—both for well stimulation as well as for routine activities germane to all upstream oil and gas development (e.g. drilling, maintenance and well cleanouts)—are not reported with SB 1281 data, though the use of such chemicals is relevant, considering their influence on oilfield wastewater quality. Spills of such chemicals (apart from produced water) may also impact oilfield wastewater management.

The SB 1281 Dataset Description

Prior to the passage of SB 1281, existing law required each oil and gas operator, on a monthly basis, to report to the Oil and Gas Supervisor, among other information, (1) the amount of water produced; (2) the number of days fluid was produced from each well; (3) which disposition[7] was made of water produced from each field and (4) the amount of fluids – gaseous and liquid – injected into each well used for enhanced recovery, underground storage of hydrocarbons and wastewater disposal.

The amendment to PRC §3227 promulgated through SB 1281 additionally required the operators to furnish to the Supervisor, for each well, the source and volume of waters—reported by water source if multiple sources are used—used and produced, including the water used to generate or make up the composition of any injected fluid or gas; volume of untreated water suitable for domestic or irrigation purposes (defined by the Division in the data dictionary associated with the SB 1281 dataset as produced water that has a total dissolved solid (TDS) concentration <10,000 mg/L); the treatment of water and the use of treated or recycled water in oil and gas field activities; and the specific disposition of all water used in or generated by *any* oil and gas field activity. When water is temporarily stored onsite, the volumes and ultimate specific use, disposal method or method of recycling, or reuse of this water must also be reported. (See Table 1 for a list of variables collected.) For each reporting requirement, if water is commingled, it must be assigned proportionately to each well. The addition of PRC §3226.3 requires the Division to annually provide to the State Water Resources Control Board (State Water Board) and the California regional water quality control boards an inventory of all unlined oil and gas field sumps. SB 1281 requires the above information to be reported on a quarterly basis. For more details about the regulation of SB 1281, including reporting requirements and codes for use by operators, see Appendix 1.

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7. A designation other than "disposition" may be more useful to describe disposal versus use of produced water.

There may be cases where the data collection could better meet the requirements in SB 1281. For instance, while SB 1281 requires operators to report treatment data along with production and injection data each month, there doesn't appear to be a standard set of codes that operators can use to report monthly treatment info per well. In addition to missing the requirement laid out in SB 1281, in some cases the way the data are collected limit the ability to compare between monthly and quarterly datasets. An example of this issue is the inconsistent use of codes between the monthly and quarterly databases. For example, the codes for sources and dispositions of water used in the production and injection (monthly) databases are coarser than the codes used for the same information in the quarterly water reporting forms, such that several categories that are broken out in quarterly reports would be recorded simply as "other" in the monthly reports. Additionally, the names of some categories differ between these databases. For instance, "surface water" (including ocean, lake, river, aqueduct, etc.) in one database is called "ocean" in another.

The accuracy, consistency and specificity of data reported to the Division under SB 1281 have not yet been verified. For instance, the Division has not compared and crosschecked the SB 1281 reporting of volumes of produced water production with their Oil and Gas Production Database.

Resolving these and other inconsistencies and verifications can improve not only data quality and utility, but also the oil and gas regulator and operator reporting experience. A deeper investigation into the data collection and design of the dataset may reveal additional opportunities for streamlining and improved utility for a range of users.

Table 1. SB 1281 Dataset at a Glance

The SB 1281 quarterly dataset is comprised of four tables, focused respectively on water production (Table Q), water injection (Table BQ), the link between production and injections (Table EQ), and water used or stored on the field that is neither produced nor injected, such as water pumped from a water well and used for dust suppression (Table FQ).

The following is a summary of key information in each table. SDIP is water "Suitable for Domestic or Irrigation Purposes," defined as below 10,000 Total Dissolved Solids.

All Tables
Operator Name & Code Quarter Field
Table Q Water Production Per Production Well
Lease Well Number & API Number Pool Name & Code Disposition SDIP (pre-treatment) Treatment method
Table EQ Water Allocation Per Well
Link from production to injection wells (that is, which injection wells receive water from which production wells)
Table BQ Water Injection
Lease Well Number & API Number Pool Name & Code Volume Injected Source SDIP (pre-treatment) Treatment (pre-injection)
Table FQ Other Water Allocation (water used on field but not produced from or injected into a well)
Volume Water Produced Source SDIP Treatment Storage

CCST SB 1281 Data Study: Goals and Structure

This white paper is the first part of an early assessment commissioned by the Division. CCST was asked to evaluate the data collection required by SB 1281. The intent of the study is to enable the state to implement the provisions of SB 1281 in the most illuminating, efficient, and effective manner possible. Where improvements can be made, an early assessment of the data will allow a prompt correction to make the program as productive as possible in the long term. The second part of this assessment will be performed through both a direct examination of the dataset and a functional evaluation achieved by working toward answering questions of import and interest to those who would use the SB 1281 dataset as a resource to answer key science and policy questions.

In this white paper, a list of key questions is provided. From this list, appropriate data parameters and scales are determined that would best allow an investigator to answer them. In the case of SB 1281, the legislation did not lay out an explicit list of questions, though as discussed above, the intent of the bill was clearly related to questions of protecting the quantity and quality of State water resources, in part through the reuse of produced water. Without clear questions to help guide the utility of data collection, it is unclear which variables on which scales are sufficient to ensure that the most critical questions can be answered.

The two phases of this study are intended first (Phase I) to define questions and propose appropriate data analyses, and second (Phase II) to examine the SB 1281 dataset by using it in conjunction with other available datasets to answer—or describe an approach to answer with more complete data—a subset of the questions outlined in Phase I. It is important to note that the goal of Phase I was to generate a list of important questions related to the intent of SB 1281 *irrespective* of the variables SB 1281 specifically requires the Division to collect. By the study's conclusion, this team will have outlined the data required to meet the spirit of SB 1281: to help decision makers, elected officials, and the public understand the oil and gas industry's impact on the availability of water for uses other than oil and gas activities, and where it is sourced, used, and reused. To this end, input was solicited from experts and practitioners to develop a list of both broad and specific questions that could be used to test the SB 1281 dataset's utility, its connectivity and compatibility with other important data resources, and its ability to contribute to answering the questions necessary to protect water resources, the environment and public health.

The *primary study question* focuses on the dataset's utility to answer key scientific and policy questions. This primary question will be evaluated through a series of *secondary evaluation questions*. For these, question categories have been defined related to water resources, public health, and environmental impact, and five broad questions have been formulated that represent large areas of research in these categories. To fully answer all of these large questions would require an enormous effort consisting of multiple quantitative analyses, and in many cases, sufficient information will likely not be available.

Box 1: Study Phases and Goals

The purpose of the CCST SB 1281 Data Study is to deliver a **preliminary assessment** of the SB 1281 dataset. The dataset will be evaluated in two ways. The first form of evaluation will be through **direct assessment** of the database. This appraisal will include but not be limited to: examining how data reporting and collection meet the SB 1281 mandate; how operators are asked to report data; the format and clarity of reporting forms; quality control protocols; and how data are managed. The second form will be a functional evaluation, achieved through **using the dataset** to work toward answering a subset of the questions posed herein. The study is being carried out in **two phases**, each phase having a distinct goal.

In Phase I, the primary goal is to **provide a list of questions** that can later guide a preliminary assessment of the SB 1281 dataset. These questions function in complementary fashion:

1. The **primary study question** is concerned with the quality and utility of the dataset itself—answering some of the operational questions associated with this primary study question will require direct assessment of the database, as highlighted above.

2. The series of **secondary evaluation questions** are broad key questions that users of the SB 1281 dataset might wish to answer. We outline **operational questions** associated with these topics, which could guide a functional evaluation of the dataset, including whether there are sufficient data to arrive at satisfactory answers, whether the dataset lends itself well to connectivity with other relevant datasets, etc.

Each of these questions will be considered in Phase I with a brief discussion of the data required to answer operational questions. Though each question in Phase I is considered relevant to the intent of SB 1281, **not all questions from Phase I will be the subject of analysis in Phase II**. A subset will be chosen during Phase II based on considerations of their tractability, significance, relevance, and feasibility.

During **Phase II**, the primary goal will be to **carry out the analyses** guided by a subset of the questions outlined in Phase I. From the narrowed list of the most tractable, significant, relevant, feasible Phase I questions, a **final research proposal will be developed as the first step in Phase II**, based on further examination of available datasets and literature. Further input from experts, stakeholders, and various appropriate agencies will also be considered when choosing the focus questions for the functional evaluation of the SB 1281 dataset.

For each secondary evaluation question, related *operational questions* that could be addressed in a quantitative manner are introduced. To the extent possible with a preliminary exploration of public data resources, it is noted whether data are available to address these questions. Each of these operational questions is designed to be examined at various spatial and temporal scales; each can also be addressed from the perspective of documenting past and present practice, or can assess the potential for future improvement. The resulting list is neither comprehensive on the very large subjects of water conservation and protection, nor intended to constitute a feasible scope of work for the functional analysis that will be performed in Phase II.

In addition to describing important questions responsive to the spirit of SB 1281 and noting data needs and availability, their suitability for further investigation during Phase II is assessed based on the following criteria:

1. **Tractability:** A qualitative assessment of data availability, quality and format required to answer the question

2. **Significance:** A qualitative assessment of the importance for water resources and public health and environmental risks and impacts

3. **Relevance:** A qualitative assessment of the potential to improve future reporting or field practices

4. **Feasibility:** An evaluation of whether the question can be productively addressed with the resources available for Phase II. Feasibility in this case refers to this study team's anticipated ability to answer a given question given financial and temporal resource constraints and not how feasible it would be to collect data required to satisfactorily answer the question.

Phase II of the project will culminate in a peer-reviewed report that will assess the quality and utility of the SB 1281 dataset (as supported by other relevant datasets) by working toward answering a subset of operational questions described in this Phase I white paper. The subset of operational questions will be chosen based on the ranking criteria defined above and a deeper investigation of available data. Questions that rank high in all four criteria are candidates for possible inclusion in Phase II of the SB 1281 Study. Questions that rank high in *significance* and *relevance*, but not in *tractability* or *feasibility* will be addressed as part of the discussion in Phase II on improving future data collection. Additionally, expert input will be taken into account when shaping the scope of the functional evaluation of the SB 1281 dataset early in Phase II. While Phase II will be an exercise in analysis and drawing from multiple available datasets to explore important questions, the primary goal will not always be to come to a final answer on the posed research questions, as much as it is to highlight where data gaps exist, data collection could be streamlined, and where and how industry reporting might be made more useful or efficient. Along the way, a synthesis of the data as they are currently available in the SB 1281 dataset is expected to yield novel contributions to the conversation on water resources in relation to oil and gas operations.

SB 1281 Research Questions

Primary Study Question: ***What is the utility of the current SB 1281 dataset to answer important questions on water resources, public health, and the environment, and are there opportunities for improvement?***

The primary goal of this study is to perform an early and preliminary assessment of the SB 1281 data set. Therefore, the overarching question driving the study is:

What is the utility of the SB 1281 dataset to answer important questions on water resources, public health, and the environment; and are there opportunities for improvement?

Operational questions that can guide an analysis of this larger question include:

- Is the dataset designed in a manner that facilitates answering the most important questions?
- Are there sufficient quality control processes in place to ensure the data are accurate and have full coverage?
- Are the data organized in a manner that facilitates connection with other important public datasets, both by the Division and by other agencies?
- Would aligning Division data stewardship practices with other multi-agency practices, such as the California Open and Transparent Water Data Act (AB 1755), significantly improve the utility of the SB 1281 dataset?
- What data gaps exist within the SB 1281 dataset, and what essential datasets do not currently exist, or are not publicly available?
- Where important data are missing, which agencies would be best suited to collect that information?

The ability to satisfactorily answer the primary study question on the utility and potential of the SB 1281 dataset depends on a functional understanding of the data included, the reporting guidelines, and how well the data contained can be used in conjunction with other existing relevant datasets. As this primary study question will be answered largely through exploration of the dataset via the following secondary questions, the operational questions listed above will be revisited in greater detail later in this report, after the secondary questions have been discussed in turn.

Secondary Evaluation Questions to evaluate the SB 1281 Dataset

The following questions are responsive to the intent of SB 1281 to inform the public about hazards, risks, and impacts of the oil and gas industry on water resources, public health, and the environment. For each secondary evaluation question, a number of operational questions—or questions that could be answered quantitatively—are outlined, a subset of which will form the foundation for a functional evaluation of the SB 1281 data set.

Secondary Question 1: *What are the sources, volumes, and quality of water used for oil and gas development and production in California?*

Secondary Question 2: *What are the characteristics/quality of produced water across the state, and how do these vary over time?*

Secondary Question 3: *How does treatment impact produced water availability as a potential resource, both within and outside of oilfields?*

Secondary Question 4: *What are the potential and actual hazards, risks and impacts to environmental and human health from various dispositions of reused water discharges to land, water, and subsurface injection?*

Secondary Question 5: *Are there unrealized opportunities to improve and expand direct and indirect reuse of produced water while limiting unintended consequences?*

Each secondary evaluation question will be discussed in terms of its associated operational questions. Each operational question is designed to be answered quantitatively or in a straightforward manner, and is presented with scores indicating the authors' assessment of its *tractability*, *significance*, *relevance*, and *feasibility*. In other words, the scores are meant to indicate how answerable the question appears to be after an initial appraisal of available relevant datasets; how important to water resources management and public or environmental health it is that the question be answered; how likely the answer is to have an impact on resource management practices; and how productively the question can be answered during Phase II of this study, given resource constraints.

Secondary Question 1: *What are the sources, volumes, and quality of water used for oil and gas development and production in California?*

Statutory Language on Source Water Reporting, Public Resources Code §3227

(a) The owner of any well shall file with the supervisor, on or before the last day of each month, for the last preceding calendar month, a statement, in the form designated by the supervisor, showing all of the following…

(4) What disposition was made of water produced from each field and the amount of fluid or gas injected into each well used for enhanced recovery, underground storage of hydrocarbons, or wastewater disposal, and any other information regarding those wells that the supervisor may require.

(5) The source of water, and volume of any water, reported in paragraph (4), including the water used to generate or make up the composition of any injected fluid or gas. Water volumes shall be reported by water source if more than one water source is used. The volume of untreated water suitable for domestic or irrigation purposes shall be reported. Commingled water shall be proportionally assigned to individual wells, as appropriate.

…

(f) For purposes of this section, the following terms have the following meanings:

(1) "Source of water" or "water source" means any of the following:

(A) The well or wells, if commingled, from which the water was produced or extracted.

(B) The water supplier, if purchased or obtained from a supplier.

(C) The point of diversion of surface water.

…

Comments on the Statutory Language:

The statute requires reporting of volumes of water used for enhanced oil recovery (EOR), underground storage of hydrocarbons, or wastewater disposal. It requires reporting on a per-well basis. Information on water use not directly tied to a well's production or injection (e.g. water from a water well used for dust control) is reported on a per operator/field basis.

Description of SB 1281 Data Collection on Water Sources

In the data summary reports posted online by the Division each quarter, the information on source water is presented in a table listing 11 categories of source water origin. (An example is presented in Table 2, showing Sources of Underground Injection Water; there are similar tables for storage and non-injection water.) Two numbers are presented for each category: total volume, and Suitable for Domestic or Irrigation Purposes (SDIP) volume.

Table 2. Sources of Underground Injection Water, Including Water Suitable for Domestic Or Irrigation Uses (defined as <10,000 mg/L TDS)

Code	Sources of Water	Total Volume	Portion Suitable for Domestic or Irrigation
01	Oil or gas well produced	81.958	159
02	Oil field water source well	1,022	1
03	Domestic fresh water system	425	339
04	Surface water	316	316
05	Class II industrial waste	0	0
06	Domestic recycled water	554	554
07	Other	155	0
08	Sale/transfer oil field produced	3,528	35
09	Recycled well stimulation treatment	0	0
10	Recycled other class II fluid	20	0
11	Recycled class II from well work operations	1	0
Total		**87,978**	**1,404**

Source: SB 1281 2016 Fourth Quarter Summary Report

Operational Questions on Source Water

Following are operational questions that could be selected for further exploration of this topic in Phase II and a preliminary qualitative assessment of each according to the criteria presented previously in this white paper. Each is scored by tractability (T), significance (S), relevance (R), and feasibility (F). A 1 is low, 5 is high, and U is unknown. A brief discussion of the rankings and descriptions of potential analytical approaches are also included for each operational question.

What are the gross water volumes, sources, and qualities used and generated on a per-operator, per-field basis? What are the net volumes of water imported and exported from oil and gas-producing reservoirs? How do these vary in space and time?

T=4*	S=5	R=5	F=5

Comment: The volumes and sources questions are relatively tractable and important questions to address. Quality of the water can be addressed only in terms of two coarse categories: SDIP/not SDIP.
** Tractability is ranked as a 4 for most aspects of this question. The exception is quality in the sense of full chemical characterization of the water; the extant data denotes the quality of the water only in terms of SDIP.*

Proposed Analytical Approach:
a. Present a series of histograms for each oil field, with categories of water on the x-axis and volumes on the y-axis. Tally volumes used in the following categories: source, SDIP, purpose. Purposes include (but are not limited to) subsurface injection, well work, well stimulation, storage, transfer to another operator, transfer/surface disposal.
b. Calculate "Net Use for Oil and Gas Development" as volume of produced water yield minus non-produced water used for oil and gas development purposes to determine a mass balance of water being exported or imported from oil and gas producing pools over the period of time during which data is available. Define "water use for oil and gas development purposes" as water used in subsurface injection, well work, and well stimulation.

What are the water volumes, sources, and qualities used for different oil and gas production methods, e.g. hydraulic fracturing and enhanced oil recovery? How do these vary in space and time?

T=4*	S=5	R=5	F=5

Comment: A relatively simple and important question to address. This analysis was undertaken as part of the SB 4 report, which found that enhanced oil recovery (a portion of which is enabled by hydraulic fracturing) uses much more water than hydraulic fracturing. The SB 1281 dataset should offer some improved resolution on the TDS of the water used for different production methods.
** Tractability is ranked as a 4 for most aspects of this question. The exception is quality in the sense of full chemical characterization of the water; the extant data denotes the quality of the water only in terms of SDIP.*

Proposed Analytical Approach: Classify pools according to the most common production techniques applied: EOR, hydraulic fracturing, or both. Calculate volume of non-produced water (broken out by SDIP) used for each production technique.

What proportion of local water production is used for oil and gas production? How do diversions of surface water, groundwater, and recycled municipal water impact water availability for other beneficial uses? How do these vary in space and time?

T=3	S=5	R=5	F=2

Comment: This is the pivotal question in water supply: whether use by the oil and gas industry represents a tradeoff for other beneficial purposes. It is a complex question to answer that can be approached at varying depths. It requires careful modeling of the water cycle and consumptive versus non-consumptive uses that are technically complex. That is, water "used" for oil and gas production is not "used up" – it may be reused, potentially multiple times, before being discharged back to groundwater or surface water. If addressed in Phase II, care should be taken to approach this question in a fashion that is manageable given time and resources available.
Proposed Analytical Approach: Compare water use for oil and gas development purposes with the 20 categories of human water use tracked on a per-county basis nationwide in the United States Geological Survey (USGS) Water Use database.

What is the intensity of water use (net water use/unit of energy produced) by production method? How does water use intensity vary over space and time?

T=2	S=4	R=3	F=2

Comment: Water use intensity varies widely by production method and is useful because it yields information both on costs and benefits. The principle challenge in addressing this question will be linking the SB 1281 database with the Division's O&G Production Database and rectifying the data. Undertaking this question may reveal insights into how to streamline and align the SB 1281 and Production Databases.
Proposed Analytical Approach: Ratio of net water use to oil and gas production information from the Division's O&G Production Database.

How does the quantity and intensity of state water use compare with other oil- and gas-producing regions in the country and globally?

T=U	S=4	R=3	F=2

Comment: Requires finding information for regions outside of California. If the information is readily available, this would be a tractable question; if not, it could be very challenging. Finding the information and aligning it with the California data could potentially be time-consuming and therefore the question was rated low for feasibility.
Proposed Analytical Approach: Calculate water use per unit of energy produced for a variety of oil-and gas-producing regions around the world.

How does the quantity and intensity of water use for oil and gas production compare with other energy production sectors?

T=2	S=5	R=5	F=2

Comment: Weighing the costs and benefits of various energy sources is of interest as California seeks to optimize its energy production portfolio. While the costs of different energy production techniques are often compared in terms of greenhouse gas emissions, impacts to water resources is an important dimension worth considering.
Proposed Analytical Approach: Compare water use intensity for California oil and gas production with existing estimates in the literature of water use intensity across energy production sectors. See Tidwell and Moreland (2016) for estimates of water use intensity for thermoelectric and hydroelectric power; energy extraction including coal, oil, natural gas, uranium and unconventional oil/gas; energy processing including oil and biofuels; and biofuel feedstock irrigation.

Candidate Operational Questions for Phase II

Secondary evaluation question #1, relating to the sources of water used in oil and gas activities, has several operational questions that can be answered to differing degrees with the available data. Of the questions posed here, at least two can be addressed productively and thoroughly and will likely be included in Phase II analyses:

- *What are the gross water volumes, sources, and qualities used and generated on a per-operator, per-field basis? What are the net volumes of water imported and exported from oil and gas-producing reservoirs? How do these vary in space and time?*

- *What are the water volumes, sources, and qualities used for different oil and gas production methods, e.g. hydraulic fracturing and enhanced oil recovery? How do these vary in space and time?*

There are a number of highly significant and relevant questions on this topic that are less tractable. At most, these questions may be partially addressed in Phase II, but aspects of each may still be worth discussing. These topics warrant further exploration and discussion, perhaps including detailed research proposals to answer questions with more illuminating data, some of which SB 1281 dataset might be modified to provide:

- *What proportion of local water production is used for oil and gas production? How do diversions of surface water, groundwater, and recycled municipal water impact water availability for other beneficial uses? How do these vary in space and time?*

- *What is the intensity of water use (net water use/unit of energy produced) by production method? How does water use intensity vary over space and time?*

- *How does the quantity and intensity of state water use compare with other oil- and gas-producing regions in the country and globally?*

- *How does the quantity and intensity of water use for oil and gas production compare with other energy production sectors?*

Secondary Question 2: *What are the characteristics/quality of produced water across the state, and how do these vary over time?*

Water is the largest byproduct by volume generated during oil and gas operations (Reynolds, 2003).[8] As California's oil-producing wells age, the ratio of water to oil and gas produced continues to increase. In 2016, California produced over 3.2 Billion barrels (Bbbl) water (almost 419,000 acre-feet) along with oil and gas (DOGGR, 2017). For comparison, California irrigates its agricultural land with roughly 34 million acre-feet a year (DWR, 2016).[9] This produced water is a mixture of injected water, formation water, hydrocarbons, and treatment chemicals (Igunnu and Chen, 2012).[10]

Produced water largely contains dissolved and dispersed oil components, dissolved minerals and naturally-occurring radioactive materials (NORM) originating from the formation, chemicals used in production, dissolved gases, and produced solids. The relative proportions of these components (and the specific constituents present) vary widely as a consequence of different geological characteristics, age of well, type of hydrocarbon produced, and extraction method.

Statutory Language on Produced Water Reporting, Public Resources Code §3227

In addition to the language relevant to source water reporting quoted under the previous secondary evaluation question, SB 1281 states:

(7) (A) The specific disposition of all water used in or generated by oil and gas field activities, including water produced from each well reported pursuant to paragraph (1). Water volumes shall be reported by disposition method if more than one disposition method is used. Commingled water shall be proportionally assigned to individual wells, as appropriate.

(B) This information shall also include the temporary onsite storage of water, as or if appropriate, and the ultimate specific use, disposal method or method of recycling, or reuse of this water.

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8. Reynolds RR. Produced Water and Associated Issues: A Manual for the Independent Operator. Oklahoma Geological Survey Open-file Report, 2003, Vol. 6, 1 – 56.

9. https://www.water.ca.gov/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency

10. Igunnu, E. T., & Chen, G. Z. (2012). Produced water treatment technologies. International Journal of Low-Carbon Technologies, 9(3), 157-177.

Description of SB 1281 Data Collection on Water Sources

In the data summary reports posted online by the Division each quarter, the information on produced water is presented in a series of tables. One lists 12 categories of water disposal methods. (An example is presented in Figure 3, showing summary statistics and a table of Water Disposal Methods, including the proportion SDIP.)

1. Volume of water produced from oil and gas extraction during the Second Quarter 2017:
   100,652 acre-feet

2. Volume of produced water suitable for domestic or irrigation purposes:
   7,062 acre-feet

3. Disposition methods of produced water, including water suitable for domestic or irrigation use:

Code	Water Disposal Methods	Total Volume	Portion Suitable for Domestic or Irrigation
01	Sump (unlined)	1,521	40
02	Sump (lined)	15	0
03	Surface water discharge	154	0
04	Domestic sewer system	292	0
05	Subsurface injection	81,793	6,321
06	Other (commercial disposal, industrial, etc.)	1,749	0
07	Sale/transfer for oil field use	3,400	1
08	Surface land discharge	122	4
09	Oil field facilities use	309	0
10	Well stimulation treatment	1,028	0
11	Sale/transfer for domestic use	10,127	696
12	Well drilling, rework, and abandonment	142	0
Total		**100,652**	**7,062**

Figure 3. Summary statistics and table from SB 1281 2017 Second Quarter Summary Report, the Division.

Operational Questions on Produced Water

Following are operational questions that could be selected for further exploration of this topic in Phase II and a preliminary qualitative assessment of each according to the criteria presented previously in this white paper. Each is scored by tractability (T), significance (S), relevance (R), and feasibility (F). A 1 is low, 5 is high, and U is unknown. A brief discussion of the rankings and descriptions of potential analytical approaches are also included for each operational question.

What is the salinity (TDS) of produced water across the state?

T=4	S=5	R=5	F=4

Comment: A straightforward question with data available for analyses for two extents. By well, there is monthly data available by well that will give salinity as SDIP or not-SDIP (SB 1281 dataset, though the averaging that operators use in many cases to report at a by-well resolution complicates interpretation). There is also TDS data available for wells throughout the state, though it needs to be clarified how these ~850 samples relate to current active well locations. (USGS Produced Water Chemistry Database; many of the samples date back to the mid-1900's.)
Proposed Analytical Approach: Use USGS data on TDS for various locations in California. Map TDS spatially by oil field. Or can plot quarterly/annual maps of SDIP/non-SDIP by well or pool from the SB 1281 dataset.

What are the chemicals used in California oilfields that are potentially part of the produced water stream?

T=3	S=5	R=5	F=4

Comment: Knowing what chemicals may be part of the produced water stream is an important prerequisite to considering whether reusing said produced water is a viable option. It is also critical to be able to understand which treatments should be required to bring produced water to an acceptable level of quality for reuse for various purposes without causing unintended consequences for other water resources, human health, and environmental quality.
Proposed Analytical Approach: South Coast Air Quality Management District 1148.2 disclosures, disclosures pursuant to AB 1328 and SB 4 reporting will be useful to help delineate some known chemicals. Provide a list of chemicals confirmed to be used in oilfields.

What is the quality, beyond TDS, of oil and gas wastewater (produced water and flowback) before treatment?

T=2	S=5	R=5	F=2

Comment: This is a critical question that pertains to the potential risks of produced water handling—and reuse in particular—yet also one that suffers from a dearth of data. As mentioned above, much of the knowledge of produced water quality in the State relies on samples collected in the 1980s and 1990s. These data are already difficult to extrapolate to current produced water quality, and even these samples were only analyzed for a very limited list of chemical constituents (certainly not for oilfield chemicals used). As such, the data gaps associated with this question are very large.
Proposed Analytical Approach: Compile available produced water quality data including but not limited to the USGS produced water chemistry database, produced water quality reporting pursuant to Central Valley Regional Water Quality Control Board (CVRWQCB) discharge permit requirements and several other databases. These produced water quality data can be mapped across geographic and potentially geological space.

What are the sources and volumes of produced water recycled for use in oilfields in the state? On local and regional scales? Compared with other oil-producing states and regions?

T=4*	S=5	R=5	F=5

Comment: The main question posed is relatively straightforward to answer, and addresses a primary focus of the SB 1281 legislation: to clarify what water can be reused within oilfields. Parsing the data on different spatial scales would provide information about the state's management of produced water as a potential resource, as well as provide a foundation for further analyses examining reuse at local scales in relation to locations of water-stressed regions. **Comparison with other oil-producing regions will depend on the availability of data and literature from other regions, which has not been ascertained at this time.*
Proposed Analytical Approach: Calculate monthly volumes of water reported as reused with codes that indicate reuse within an oilfield, mapped by source location. (Separate used within same oilfield and transported to another oilfield.)

What are the sources and volumes of produced water reused outside of oilfields? How do these quantities and proportions compare with other oil-producing states and regions?

T=4*	S=5	R=5	F=5

Comment: The main question posed is relatively straightforward to answer, and addresses the spirit of the SB 1281 legislation, though the conversation around reuse of produced water outside of the oilfield has intensified since SB 1281 was chaptered. Parsing the data on various spatial scales would provide information about the state's management of produced water as a potential resource outside the oilfield. Additionally, this question is relevant to discussions of reuse at local scales in relation to locations of water-stressed regions. **Comparison with other oil-producing regions will depend on the availability of data and literature from other regions, which has not been ascertained at this time.*
Proposed Analytical Approach: Calculate monthly volumes of water reported as reused with codes that indicate application outside of an oil field.

Candidate Operational Questions for Phase II

Secondary evaluation question #2, relating to produced water throughout California, has several operational questions that can be answered to differing degrees with the available data. Of the questions posed here, at least three can be addressed productively and thoroughly in Phase II analyses:

- *What is the salinity of produced water across the state?*

- *What are the sources and volumes of produced water recycled for use in oilfields in the state? On local and regional scales? Compared with other oil-producing states and regions?*

- *What are the sources and volumes of produced water recycled for use in applications beyond the oilfield? How do these quantities compare with other oil-producing states and regions?*

Other questions posed on this subject are highly significant and relevant, but are less tractable. At most, these questions may be partially addressed in Phase II, but aspects of each may still be worth discussing. These topics warrant further exploration and discussion, perhaps including detailed research proposals to answer questions with more illuminating data, some of which SB 1281 dataset might be modified to provide:

- *What are the chemicals used in California oilfields that are potentially part of the produced water stream?*

- *What is the quality of wastewater (produced water and flowback) before treatment?*

Secondary Question 3: How does treatment impact produced water availability as a potential resource, both within and outside of oilfields?

Most frequently, discussions of produced water are centered on the high level of total dissolved solids (TDS) it contains. But a number of other contaminants are often present, including oil and grease, suspended solids, dispersed oil, dissolved and volatile organic compounds, heavy metals, radionuclides, dissolved gases, bacteria, and chemical additives used in production such as biocides, scale and corrosion inhibitors. While there are a number of constituents of known concern, there are also many that are known unknowns, and still more that are unknown unknowns.

Various contaminants may present more or less concern, depending on the destination of the produced water, and treatment trains are applied to bring the overall quality of the water to a level appropriate for its intended use. Generally, the treatment of produced water can happen in phases, where contaminants are removed from water in phases, from the bulk of oil and gas to heavy metals and organisms. Each treatment phase involves different technologies and is applied according to intended destination and regulations.

Statistory Language on produced water treatment, Public Resources Code §3227

(a) The owner of any well shall file with the supervisor, on or before the last day of each month, for the last preceding calendar month, a statement, in the form designated by the supervisor, showing all of the following…

> *(6) The treatment of water and the use of treated or recycled water in oil and gas field activities, including, but not limited to, exploration, development, and production…*

(c) …

> *(2) Notwithstanding subdivision (a), the owner of any well shall file with the supervisor, on a quarterly basis, a statement containing the information required to be reported pursuant to paragraphs (5), (6), and (7) of subdivision (a) in the form designated by the supervisor.*

Comments on the Statutory Language:

The statute requires reporting of the method of treatment of water, and what volumes of treated or recycled water is used specifically in oil and gas activities. It requires reporting on a per-well basis.

Description of SB 1281 Data Collection on Water Treatment

In the quarterly reports released by the Division, the information on treated water is presented in tables listing—for produced water, injected water (treated pre-injection), and non-injected and stored water—31 categories of treatment. There are only five categories (including "other") of specific treatment methods tracked through reporting by operators, but they are reported as treatment trains, such that various combinations of treatment methods are reported. (See Table 3 from a recent quarterly report.) Reporting this way may give additional insight into not only the input water but also the intended use for such water.

Table 3. From 2016 4th Quarter Water Report, the Division.

4. Produced water treatment methods:

Water Treatment Methods	**Total Volume Treated**
De-oling	50,517
De-oling and Disinfection	9,885
De-oling, Disinfection, and Desalinization	3
De-oling, Disinfection, Desalinization, and Membrane	0
De-oling, Disinfection, Desalinization, Membrane, and Other	0
De-oling, Disinfection, Desalinization, and Other	0
De-oling, Disinfection, and Membrane	0
De-oling, Disinfection, Membrane, and Other	0
De-oling, Disinfection, and Other	213
De-oling, and Desalinization	11,393
De-oling, Desalinization, and Membrane	2
De-oling, Desalinization, Membrane, and Other	0
De-oling, Desalinization, and Other	0
De-oling, and Membrane	5,310
De-oling, Membrane, and Other	0
De-oling, and Other	20,738
Disinfection	1
Disinfection, and Desalinization	0
Disinfection, Desalinization, and Membrane	0
Disinfection, Desalinization, Membrane, and Other	0
Disinfection, Desalinization, and Other	0
Disinfection, and Membrane	0
Disinfection, Membrane, and Other	0
Disinfection, and Other	11
Desalinization	0
Desalinization, and Membrane	0
Desalinization, Membrane, and Other	0
Desalinization, and Other	0
Membrane	364
Membrane, and Other	0
Other	875
Total	**99,312***

**1,242 acre-feet of water was reported as untreated.*

Operational Questions on Treated Produced Water

Below are operational questions that could be selected for further exploration of this topic in Phase II and an assessment of each according to the criteria presented previously in this white paper. Each is scored by tractability (T), significance (S), relevance (R), and feasibility (F). A 1 is low, 5 is high, and U is unknown. A brief discussion on the rankings and descriptions of potential analytical approaches are also included for each operational question.

What proportion of produced water is currently treated prior to disposal or any reuse application in California? How does this quantity compare to other oil-producing states and regions?

T=5	S=5	R=5	F=5

Comment: The primary question is a relatively straightforward and important question to address, and the California dataset appears to be sufficient. The follow-up about comparison with other oil-producing regions will depend on what information is available beyond California, and this context will be applied to all following operational questions as feasible.
Proposed Analytical Approach: Calculate total volumes of produced water treated as proportion of all produced water. This analysis could be performed at various spatial and temporal scales (as appropriate depending on data/literature for other regions for comparison). Timescales could be quarterly or greater, given SB 1281 dataset.

Of the quantities of produced water treated, what proportion is sent for disposal? What proportion is reused within the oilfield? What proportion is reused outside of the oilfield?

T=5	S=5	R=5	F=5

Comment: This is a relatively straightforward and important question to answer. This question addresses part of what SB 1281 was implemented to ascertain: whether California operators are using produced water as a resource, even when it must be treated to do so, and how these treated volumes are currently being applied.
Proposed Analytical Approach: At statewide and oilfield scales, present stacked bar plots of total volumes treated, divided into volumes of treated produced water disposed, used within and outside of oilfields. It is also possible to examine spatial distribution (by oilfield) of proportion reused within and outside of oilfields versus disposed.

Which operators or areas of the state reuse the most produced water by volume and proportion?

T=5	S=5	R=5	F=5

Comment: A relatively straightforward and important question to answer. This question addresses part of what SB 1281 intends to ascertain: whether California operators are using produced water as a resource, even when it must be treated to do so, and how these treated volumes are currently being applied.
Proposed Analytical Approach: As above, present stacked bar plots of total volumes treated by operator and region. Then divide into volumes of treated produced water that is disposed or reused. Oilfields could also be ranked by amount of treated water reused, within and/or outside of the oilfield.

Which applications are currently the largest destinations for treated produced water in California?

T=4	S=5	R=5	F=4

Comment: A relatively straightforward and important question to answer precisely, especially for applications besides reinjection for disposal. This question addresses part of what SB 1281 intends to ascertain: whether California operators are using produced water as a resource, even when it must be treated to do so, and how these treated volumes are currently being applied. The resolution of this answer, especially with regard to specific reuse categories, may be somewhat limited by the fact that operators are not given many different codes for different reuse applications off the oilfield; some of this information may be filled in with data from discharge permits.
Proposed Analytical Approach: At statewide and oilfield scales, rank by calculated volumes of reused, treated produced water. Over time, at state or oilfield scale, present stacked bar plots of total volumes treated, divided into volumes of treated produced water intended for various uses. Examine spatial distribution (by oilfield) of top reuse application. Analyze changes in reuse categories over time by presenting time series of volumes of treated water intended for specific reuse categories.

Which treatment options for produced water are currently in use for which produced water reuse categories?

T=2*	S=5	R=5	F=1*

Comment: A keystone concept in water reuse is that water quality should be "fit-for-purpose." That is, water should be treated to reach a quality appropriate for its intended use. This question aims to illuminate the types of treatment applied in different categories of produced water reuse. The results would be key to assessing the potential hazards and risks to public health and the environment from these practices. While an economic assessment is out of scope for this project, addressing this question would provide critical variables in the assessment of the economics of continued or expanded produced water reuse. However, the SB 1281 dataset provides limited information on treatment technologies in use, as the operator codes for reporting treatment group distinct technologies together. For example, operators report "Membrane Treatment," but do not differentiate between various membrane separation processes and materials. These variables have significant bearing on cost and energy use. Consequently, a detailed and nuanced answer to this question would be relatively intractable with the current dataset. **The question can be addressed with the current SB 1281 dataset in a general fashion that is highly feasible and tractable, but such an approach would reduce the significance and relevance.*
Proposed Analytical Approach: Evaluate the volumes of water treated with the general treatment categories as currently reported in the SB 1281 dataset. Make recommendations on how to refine the reporting categories in the future.

Are treatment methods currently in use in California the most effective options?

T=2*	S=5	R=5	F=2*

Comment: A complete answer to this question would provide important context for decision makers and operators in California, about the range of available and tested technologies and how those compare to technologies currently favored in California. However, the answer to this question is limited by the coarse codes provided to operators to report treatments. (See above for more discussion in the same vein.) **The question can be answered in general terms, but given the variability of treatment technologies within a single type of treatment code as supplied by the Division, the significance and relevance of the attainable answer would be reduced considerably.*
Proposed Analytical Approach: To answer the general question, a literature review to assess treatment types in use and which have been assessed for produced water is actionable. The background provided by the literature review can be used as a foundation for comparison to the volumes treated with various general categories of treatments. However, the utility of the answer is diminished without additional information about specific treatment technologies, materials, and chemistry applied.

What quality of produced water is appropriate for which uses, from regulatory, environmental, and public health perspectives?

T=U	S=5	R=5	F=3

Comment: Answers to this question are crucial to begin to evaluate potential risks of reusing produced water, especially outside of the oilfield. The tractability of this question is uncertain because it depends on whether suitable quality has been determined for all uses and for all relevant produced water constituents, and the extent of the literature on this subject is not known at this point.
Proposed Analytical Approach: Review California and Federal codes for minimum quality requirements, and literature for impacts of assorted constituents in various reuse applications of both oilfield produced water and other waters currently reused, such as municipal wastewater. If the literature does not contain clear risk/hazard assessments of all produced water constituents, a full evaluation of what is appropriate for various reuse purposes may not be possible until these are established. As such, this question would likely be approached through the development of an analytical framework through which data gaps are identified and guidance from analogous situations (e.g. addressing constituents of emerging concern, or "CECs," in municipal wastewater reuse) would be drawn upon to inform guidance on a way forward.

What types of waste streams are created through treatment of produced water and how are they handled?

T=3	S=4	R=4	F=3

Comment: Determining what waste streams are being created through any treatment action is important for understanding the potential impacts and therefore viability of any given treatment strategy. Additionally, the risks of storage, handling and disposal, and associated costs may change the practicality of various treatment options. As mentioned above, the data provided in the SB 1281 dataset will not be sufficient to provide accurate estimates of waste volumes and types produced, but a general discussion of types of waste streams and orders of magnitude may be possible.
Proposed Analytical Approach: Literature review for identifying waste products, interviews and searching State and Federal code for handling practices and expectations, and the answer to previous operational questions to estimate what quantities of waste streams are currently being created based on reported treatment volumes and general methods. It may also be possible to conduct a relatively crude mass balance analysis based on the salinity of produced water, the volume to be reused, and the required TDS concentrations prior to application. This could result in an estimate of the mass of the suspended and chemical load of produced water that could be separated from a given volume of water, as a proxy for the mass of the waste stream.

Candidate Operational Questions for Phase II

Secondary evaluation question #3, relating to treatment of produced water, features a number of operational questions that could be addressed productively in Phase II, though not all will be suitable for full analyses. General questions about whether produced water is treated, and what general treatment categories are applied, appear to be informed by the SB 1281 dataset. However, any deeper dive into the specifics of treatment types applied prior to disposal or various reuse purposes is hampered by the coarse resolution of the operator reporting codes. Much of the value gained from answering questions of this nature would require a finer categorization of the reported data; specific treatment information, such as processes and materials involved, would better characterize the potential economic, energy, and environmental and public health costs of produced water treatment across the state, and would be useful for a wide range of data end users.

Candidates for a thorough analysis in Phase II:

- *What proportion of produced water is currently treated prior to disposal or any reuse application in California?*
- *Of the quantities of produced water treated, what proportion is sent for disposal? What proportion is reused within the oilfield? What proportion is reused outside of the oilfield?*
- *Which operators or areas of the state reuse the most produced water by volume and proportion?*
- *What applications are currently the largest destinations for treated produced water?*

Candidates for lean analyses or further discussion (without analysis) in Phase II:

- *Which treatment options for produced water are currently in use for which produced water reuse categories?*
- *Are treatment methods currently in use in California the most effective options?*
- *What quality of produced water is appropriate for which uses, from regulatory, environmental, and public health perspectives?*
- *What types of waste streams are created through treatment of produced water and how are they handled?*

Secondary Question 4: ***What are the potential and actual hazards, risks and impacts to environmental and human health from various dispositions of reused water discharges to land, water, and subsurface injection?***

The SB 1281 dataset is compiled in large part to provide data about key variables that are required to answer questions related to environmental and public health hazards, risks and impacts. While the SB 1281 database is primarily concerned with issues of *quantity* of source and produced water as opposed to *quality*, both are key elements necessary to help determine potential risk factors and impacts to environmental and public health and to help guide potential modifications of data collection under SB 1281 in the future.

The public health and environmental hazards associated with produced water handling, disposal, and reuse are inextricably tied to the chemical composition of produced water. Chemical composition of produced water is determined by geogenic compounds from the subsurface, chemical additives to facilitate and maintain oil and gas production, and the synergistic byproducts and daughter products associated with the interactions between these compounds and other extrinsic factors such as temperature, pressure, exposure to air, and treatment approaches.

It is important to investigate environmental and human health hazards, risks and impacts of the methods through which produced water is managed, used, and reused. To date, produced water has been reused in the following ways:

1. Onsite re-injection to maintain formation pressure or for chemical enhanced oil recovery (EOR)

2. Onsite reuse to produce steam for thermal EOR

3. Onsite reuse to regenerate ion exchange (IEX) resins

4. Agricultural irrigation

5. Industrial makeup fresh water for dust suppression, concrete manufacture, cooling water, boiler feed, equipment washing, etc.

6. Offsite industrial reuse as clean brine for IEX regeneration, etc.

7. Indirect potable water reuse

Currently, produced water in California is predominantly re-injected into the subsurface (via Underground Injection Control, or UIC, wells) for EOR and for Class II UIC disposal, and a smaller proportion – predominantly but not exclusively, in the Southern San Joaquin Valley (SJV) – is discharged to land for agricultural irrigation, livestock watering, dust suppression, aquifer recharge and other purposes. The produced water dispositions that involve discharge to land and reuse for EOR are generally classified as produced water "reuse". A number of key questions with respect to the potential hazards, risks and impacts to environmental and human health associated with these practices can be found below.

Operational Questions on the Environmental and Human Health Risks of Produced Water Injection and Reuse

Below are operational questions that could be selected for further exploration of this topic in Phase II and an assessment of each according to the criteria presented previously in this white paper. Each is scored by tractability (T), significance (S), relevance (R), and feasibility (F). A 1 is low, 5 is high, and U is unknown. A brief discussion of the rankings and descriptions of potential analytical approaches are also included for each operational question.

Given uncertainties in quality of produced water, what steps have been taken to ensure adequate quality of post-treated produced water for specific purposes?

T=3	S=5	R=5	F=3

Comment: Given the uncertainty with respect to the quality (beyond salinity) of produced water across the state, it is imperative to understand how operators and regulators have approached the issue of ensuring that produced water, post treatment, does not pose risks to water resources, public health, and the environment. In the case of municipal wastewater reuse, water managers often rely on the treatment technology as opposed to direct water quality monitoring to determine "fit for purpose." However, CECs (e.g., pharmaceuticals and other estrogenic and mutagenic compounds) may not be adequately removed or neutralized—and can even be exacerbated by—existing treatment approaches (Drewes et al., 2018). Even if these CECs are mitigated through treatment (for instance via post treatment monitoring), there is marked complexity in arriving at risk-based conclusions in a scientifically rigorous fashion. The issue of oilfield wastewater reuse may pose analogous challenges given the uncertainty of the chemical composition of the resource prior to treatment. As such, it is appropriate to investigate the approaches that operators and regulators have taken to ensure that the risks of public health, environmental, and water resource impacts are minimal across reuse purposes to date, and how the uncertainty could be reduced and constrained.
Proposed Analytical Approach: The analysis of such a question would likely not result in definitive quantitative conclusions, but rather would result in a detailed analytical framework and science landscape analysis that would inform how to answer these questions over time. To start, a review of the post-treatment produced water requirements in discharge permits issued by the regional water boards in California would enable the research team to begin to ascertain whether the requirements to ensure post treatment water quality are sufficient given knowledge of the variability and chemical composition of produced water in those regions. Second, a review of post-treatment produced water quality data under these discharge permits should be undertaken. Finally, a review of approaches to this issue in the municipal wastewater space with respect to the determination of efficacy of removal of CECs and reduction in mutagenicity, toxicity, etc. would be appropriate to compare to how this issue is being handled in the context of oil and gas produced water reuse.

Percolation Pits Used for Aquifer Recharge

What is the chemical composition of and/or chemicals of human health and environmental concern in produced water discharged to percolation pits?

T=2	S=5	R=5	F=3

Comment: Given the finding in the SB 4 report that a high proportion of the percolation pits in the southern SJV are located above or near low TDS groundwater, it is critical to understand the chemical composition of the produced water being discharged to these pits. This is further underscored by the recent determination by the CVRWQCB that discharge of produced water to a percolation pit has contaminated aquifers defined as USDWs more than 2 miles away (CVWRQCB, 2018). The USGS has also recently issued findings that percolation pits are impacting protected groundwater. The tractability of this question is hampered by the lack of reporting of the quality and chemical composition of produced water discharged to pits in the State.
Proposed Analytical Approach: Gather, compare, and summarize produced water quality data associated with percolation pits. Identify hazards to the environment and human health using chemical-specific physical properties and toxicity information.

What volume of produced water is discharged to percolation pits and surface waterways?

T=4	S=5	R=5	F=4

Comment: This question is answerable using the SB 1281 dataset but given the number of pits known to be relatively unregulated there may be uncertainty in the accuracy of the data.
Proposed Analytical Approach: Calculate produced water volume disposed via “Sump (unlined) - Evaporation and Percolation” and “Surface Water Discharge” water disposition categories in the SB 1281 dataset.

Where are the locations of these percolation pits geographically with respect to groundwater that is currently used or in the future could be used for drinking, food crop irrigation and other activities with potential human exposure pathways?

T=4	S=5	R=5	F=4

Comment: There appears to be significantly more data on location of percolation pits since the publication of CCST’s SB 4 report in 2015. The CVRWQCB has done significant work to document and locate percolation pits to bring them under regulation since 2015. Additionally, the resolution of groundwater salinity throughout the state has improved through efforts by USGS and other agencies since 2015 as well. As such it is appropriate to update this analysis.
Proposed Analytical Approach: Use percolation pit reporting (coordinates or Global ID information) to map percolation pit locations. Summarize pit locations by water district and determine proximity to drinking water wells and protected groundwater by spatial extent and depth.

Produced Water Reused for Agricultural Irrigation and Livestock Watering

What is the chemical composition of and/or what are the chemicals of concern in produced water discharged for use in food crop irrigation and livestock watering?

T=3	S=5	R=5	F=3

Comment: Given that this is one of the current and rapidly expanding uses of produced water with the most direct exposure pathways to human populations, this question is paramount to include in this assessment. This question is also critical beyond California, given that the federal Environmental Protection Agency (EPA) is considering the promulgation of regulations for this practice across the United States and is looking at California's approaches to inform its decision making.
Proposed Analytical Approach: Summarize existing produced water composition information from the CVRWQCB, Food Safety Expert Panel, and the Cawelo Water District. Collate and analyze produced water quality monitoring reporting pursuant to waste discharge permits for use in food crop irrigation and livestock watering.

What volume of produced water is discharged to water districts for food crop irrigation and livestock watering?

T=5	S=5	R=5	F=5

Comment: Answering this question is also important for assessments of agricultural, environmental and human health, and associated environmental and exposure pathways. The quality and resolution of data to answer this question appears relatively high.
Proposed Analytical Approach: Calculate volume of produced water disposed via "Sale/Transfer – Domestic Use" as a water disposition category in the SB 1281 dataset and in waste discharge permits and associated reporting.

Where, geographically, is produced water sent for reuse in agricultural irrigation?

T=5	S=5	R=5	F=5

Comment: This question is critical to answer other questions about human and environmental health hazards, risks and impacts of the practice.
Proposed Analytical Approach: Identify "Name of Water Source/Disposal Recipient" for produced water disposition categorized as "Sale/Transfer – Domestic Use." Determine agricultural areas served by disposal recipients identified by reaching out to Water Districts or operators if necessary. The SB 1281 research team may also be able to draw on concurrent work being undertaken by the Vengosh Lab at Duke University on this topic.

Incidence and Implications of Produced Water Mixing with Current Drinking Water Sources

Are there communities in California and/or households that are currently drinking from water supplies that have been intentionally or unintentionally mixed with or been impacted by produced water?

T=3	S=5	R=5	F=3

Comment: This question is important from a human exposure perspective and has not, to date, been answered. The breadth of this question will reach across produced water dispositions (including UIC injections and discharge to surface). It is unlikely that providing a fully detailed answer to this question is possible at this time, but it is likely possible to highlight the geographic areas and depth of aquifers that both serve as drinking water and have produced water activity within or near them. The SB 1281 Dataset will provide information about disposal/reuse locations, information that is essential to determining potential impacts to current drinking water sources. Answering this question will also require information from external datasets focused on drinking water sources for CA populations.
Proposed Analytical Approach: Identify spatial extent and depth of water wells and aquifers that serve as drinking water sources in proximity to produced water reuse/disposal (ascertained from SB 1281 dataset). Determine water source information for public water systems and populations they serve using the CDPH Water Systems Geographic Reporting Tool and by contacting local public water suppliers.

Where in California is there evidence or potential risk of produced water intermixing with groundwater resources that should be protected based on the definition of underground sources of drinking water (USDWs) under the Safe Drinking Water Act (SDWA)?

T=3	S=5	R=5	F=3

Comment: This question should be assessed across all produced water disposition methods, but with special emphasis on UIC well injections and the process and criteria used by the Division to determine aquifer exemptions.
Proposed Analytical Approach: Overlay locations where produced water has been reused and disposed of on the areal extent of aquifers known to be subject to protection as USDWs (with a TDS < 10,000 mg/L). Next, for aquifers with available spatial and water quality data, identify aquifers that meet USDW standards in horizontal and vertical proximity to produced water reuse/disposal activities. Create a heat map or other data visualization that highlights the qualitative risk of aquifers of high quality being collocated with produced water handling, disposal, and reuse (ascertained from the SB 1281 dataset).

Produced Water Reused for Dust Control, Road Maintenance and De-Icing

How much produced water is used for road spreading, dust suppression and other types of ice or dust control in California and what are the potential pathways through which human populations can be exposed to chemicals of health concern?

T=4	S=4	R=4	F=4

Comment: Given the extent to which these reuse processes are occurring in the northeast, the identification of risks to surface and groundwater resources in recent studies, and the lack of characterization of these practices in California, it is important to seek answers to these questions. This analysis would be nested within an environmental and exposure pathway assessment.
Proposed Analytical Approach: Calculate produced water volume disposed of via the "Surface Discharge – Land" water disposition category in the SB 1281 dataset and obtain other data via discharge permits issued by regional water quality control boards. Conduct literature review to summarize environmental and exposure pathways associated with reuse methods involving surface discharge to land.

Produced Water Spills

How often do spills of produced water occur, and at what points in the oil and gas life cycle? What are the volumes and what are the chemical constituents found in this produced water?

T=2	S=3	R=3	F=2

Comment: Data on produced water spills in California is particularly poor and so understanding of the volume and quality of produced water that is spilled in the State is poorly characterized. Given that this was covered in CCST's SB 4 report, it is likely an environmental pathway not worth much analytical time. It is, however, an opportunity to perhaps amend SB 1281 or other datasets to require more accurate and frequent reporting on with a lower volumetric reporting threshold.
Proposed Analytical Approach: Discuss absence of spill information from SB 1281 dataset. Discuss strengths and limitations of existing OES Spills Dataset to characterize quantity and quality of spills associated with oil and gas production in California.

Produced Water Reused Infield and Disposed of via Class II UIC Wells

What volume of produced water is injected into UIC wells annually?

T=5	S=4	R=5	F=5

Comment: This question is easily answered using available data in the SB 1281 and the Oil and Gas Production databases maintained by the Division. These data will act as a building block—in conjunction with water quality and geological data—to assess hazards and risks to groundwater resources.
Proposed Analytical Approach: Calculate volume of produced water disposed via "Subsurface injection" water disposition category in the SB 1281 dataset.

What is the quality of produced water that is injected into Class II UIC wells across space and time, particularly in zones that contain(ed) groundwater that meets the definition of USDWs?

T=2	S=5	R=5	F=2

Comment: To some extent from a current and in particular from a future public health and water quality perspective, it is particularly important to assess the quality of produced water used in Class II (EOR) and Class II (disposal) wells that have been injected in geological strata containing water quality that meets the definition of USDWs under the SDWA. Groundwater of these salinities would be expected to be highly sought after as droughts become longer and more intense.
Proposed Analytical Approach: Use API and associated geospatial information for Class II UIC wells to identify locations of wells injecting produced water over time. Calculate volume of produced water injected via "Subsurface Injection" waste disposition category that is and that is not categorized as SDIP based on TDS. Characterize produced water quality from well stimulation reporting (SB 4), monitoring efforts associated with aquifer exemptions, and additional chemical disclosure. Assess the locations of aquifer exemptions determined by the Division in collaboration of the State Water Board.

What is the incidence and potential for the loss of UIC well and geological zonal isolation leading to contamination of nearby aquifers that should be protected according to the definition of USDWs?

T=3	S=5	R=5	F=2

Comment: Oil and gas development and the UIC program depends on accurate information about zonal isolation in wellbores and in the subsurface geology to make decisions and determinations of risk to nearby groundwater resources. This question would require substantial resources and inter-disciplinary expertise to answer. Given the likely answerability, but only with substantial resources, this question is not a likely candidate for inclusion in Phase II.
Proposed Analytical Approach: Identify risk factors associated with loss of zonal isolation for UIC wells by reviewing the literature and government reports, as well as mechanical integrity testing and groundwater monitoring data, if available.

Have UIC wells injected produced water into aquifers that are currently or could be in the future used for drinking, irrigation or other domestic consumption practices?

T=3	S=5	R=5	F=3

Comment: This is a very important question and the answers can hold implications for greater oversight of the UIC program moving forward. However, this question is currently being addressed through other processes, such as the SB 83 (Committee on Budget and Fiscal Review, 2015) UIC independent oversight panel.
Proposed Analytical Approach: Identify regulatory framework for aquifer exemptions (including consideration of groundwater salinity) and identify current aquifer exemptions in California. Identify location and depth of private water wells near aquifers with UIC practices. Determine water source information for public water systems and populations they serve using the CDPH Water Systems Geographic Reporting Tool and by contacting local public water suppliers.

Are current criteria for decision making regarding the siting of UIC activities and aquifer exemptions appropriate to protect groundwater resources and human health now and in the future?

T=3	S=5	R=5	F=4

Comment: This is a critical assessment to undertake with respect to the potential for degradation of groundwater resources that are currently or could in the future be used for drinking water or other domestic or municipal purposed as defined by the SDWA. However, this question is currently being addressed through other processes, such as the SB 83 UIC independent oversight panel.
Proposed Analytical Approach: Review permitting process for UIC siting and aquifer exemptions. Compare groundwater quality considerations in the permitting process to other protected groundwater water resources within the state and in other oil and gas producing states.

General Public and Environmental Health Pathways and Risk Factor Assessments

What are the known potential exposure pathways and risk factors through which ecosystems and humans can be exposed to chemicals of concern in produced water? What are the potential environmental and public health impacts associated with these exposures?

T=5	S=5	R=5	F=5

Comment: While there is certainly a dearth of data and conclusions on public health and water resource impacts attributable to produced water handling, disposal and reuse in California, there is a fairly well-established understanding of what the potential pathways through which humans can be exposed to chemicals of concern in produced water are. This was well laid out in CCST's SB 4 report. These identified pathways were referred to as "risk factors" and this could be expanded upon and summarized depending upon findings and conclusions reached in this report. However, it would be addressed entirely by literature review and not by the SB 1281 dataset, and consequently does not appear to be fully in the scope of this study.
Proposed Analytical Approach: Expand upon and/or summarize pathways and risk factors identified previously in the CCST SB 4 report.

What is the potential for the accumulation of chemicals of concern in produced water in wild ecosystems, agricultural soils, plants and animals used for human consumption, and in human tissue? How do various oil and gas production methods and produced water dispositions and practices modify this potential?

T=5	S=5	R=5	F=5

Comment: Accumulation and bioaccumulation potential are critical metrics to determine the potential risk of a substance should it be emitted to the environment or exposed to humans. Chemical constituents that bioaccumulate are not readily excreted from tissues and as such can build up. Bioaccumulation in human food sources is particularly concerning given that this accumulation in food can be magnified in human tissue when these foods are consumed regularly. Using a combination of chemical disclosures from the oil industry in the SB 4 database, FracFocus, SCAQMD and emerging chemical additive datasets from the CVRWQCB as well as available geogenic chemical data from USGS and others, it would be possible to gain access to more information on the bioaccumulative potential of chemicals in produced water. This would be particularly relevant for assessing risks of produced water discharge to agriculture and potentially for indirect potable reuse.
Proposed Analytical Approach: Using a combination of chemical disclosures from the oil industry in the SB 4 database, FracFocus, SCAQMD and emerging chemical additive datasets from the CVRWQCB as well as available geogenic chemical data from USGS and others, identify chemicals in produced water and their bioaccumulative potential. Perform a brief literature review to determine if and how oil and gas production methods or produced water disposition practices may modify bioaccumulative potential of identified compounds.

Candidate Operational Questions for Phase II

Secondary evaluation question #4, relating to environmental and human health risks of produced water injection and reuse, had a large number of very significant operational questions that had relatively low tractability, as they rely heavily on data that are not being collected. The mismatch of questions having high significance and relevance but low tractability and feasibility highlights the need for good data about the quality of produced water in California, beyond simple categories of salinity. A discussion about which variables are needed will be presented in Phase II. Even without a dataset focused on water quality data, at least four operational questions have been identified as able to be addressed in a productive way using the SB 1281 dataset to support other datasets. These questions may be included for analysis in Phase II:

- *Where are the locations of these percolation pits geographically with respect to groundwater that is currently used or in the future could be used for drinking, food crop irrigation and other activities with potential human exposure pathways?*
- *What volume of produced water is discharged to water districts for food crop irrigation and livestock watering?*
- *Where, geographically, is produced water sent for reuse in agricultural irrigation?*
- *What volume of produced water is injected into UIC wells annually?*

The following are highly significant or relevant questions, but are less tractable than those listed above. Some of these may at most be only partially addressed in Phase II, but warrant further exploration and discussion, perhaps including detailed research proposals to answer questions with appropriate data:

- *Given uncertainties in quality of produced water, what steps have been taken to ensure adequate quality of post-treated produced water for specific purposes?*
- *What is the chemical composition of and/or chemicals of human health and environmental concern in produced water discharged to percolation pits?*
- *What volume of produced water is discharged to percolation pits and surface waterways?*
- *What is the chemical composition of and/or what are the chemicals of concern in produced water discharged for use in food crop irrigation and livestock watering?*
- *Are there communities in California and/or households that are currently drinking from water supplies that have been intentionally or unintentionally mixed with or been impacted by produced water?*

- *Where in California is there evidence or potential risks of intermixing of produced water with groundwater resources that should be protected based on the definition of underground sources of drinking water (USDWs) under the Safe Drinking Water Act (SDWA)?*

- *How much produced water is used for road spreading, dust suppression and other types of ice or dust control in California and what are the potential pathways through which human populations can be exposed to chemicals of health concern?*

- *How often do spills of produced water occur, and at what points in the oil and gas life cycle? What are the volumes and what are the chemical constituents found in this produced water?*

- *What is the quality of produced water that is injected into Class II UIC wells across space and time, particularly in zones that contain(ed) groundwater that meets the definition of USDWs?*

- *What is the incidence and potential for the loss of UIC well and geological zonal isolation leading to contamination of nearby aquifers that should be protected according to the definition of USDWs?*

The following operational questions, while relevant to the SB 1281 intent, will likely not be addressed through data analysis in Phase II. Though these are essential questions, they are either not supported by enough data, have or will be answered by other studies, or are not clearly within the scope of the SB 1281 Study, which is focused on testing the SB 1281 database, and therefore must require the database to answer it. Material related to these questions may still be incorporated in background material in the Phase II report.

- *Have UIC wells injected produced water into aquifers that are currently or could be in the future used for drinking, irrigation or other domestic consumption practices?*

- *Are current criteria for decision making regarding the siting of UIC activities and aquifer exemptions appropriate to protect groundwater resources and human health now and in the future?*

- *What are the known potential exposure pathways and risk factors through which ecosystems and humans can be exposed to chemicals of concern in produced water? What are the potential environmental and public health impacts associated with these exposures?*

- *What is the potential for the accumulation of chemicals of concern in produced water in wild ecosystems, agricultural soils, plants and animals used for human consumption, and in human tissue? How do various oil and gas production methods and produced water dispositions and practices modify this potential?*

Secondary Question 5: ***Are there unrealized opportunities to reduce stress on other water resources, including conservation and efficiency, improving and expanding direct and indirect reuse of produced water?***

Given the various produced water disposition methods described previously and concerns about water scarcity in California, it is important to investigate the potential for increased reuse of produced water. Produced water in California is predominantly re-injected into Class II wells for disposal or enhanced oil recovery. Meanwhile, a smaller proportion is discharged for reuse at the surface via agricultural irrigation, livestock watering, dust suppression, and aquifer recharge. Produced water is also directed to percolation pits, which are commonly thought of as a category of disposal, but which in some cases should be evaluated as a form of indirect reuse.

The SB 1281 dataset provides information about quantities of water that are “suitable for domestic or irrigation purposes” (SDIP, defined as <10,000 ppm TDS), as well as information about how this water is reused or disposed. Further investigation is warranted as to how much and where throughout the state produced water categorized as SDIP is being disposed of (e.g., via subsurface injection for disposal) that could otherwise be reused either within or outside of oilfields.

Of course, as noted previously, the sole reliance on salinity and other standard water quality measures may lead to negative unintended consequences for public health and the environment. A more holistic view of water quality may be needed to ensure that produced water reuse does not pose potential risks. The environmental and human health considerations of reuse are discussed in detail in secondary evaluation question 4 and intermittently in other questions within this white paper. The operational questions included below address additional considerations regarding the potential expansion of produced water reuse.

Operational Questions on the opportunities to improve management of water sources via conservation and produced water reuse

Below are operational questions that could be selected for further exploration of this topic in Phase II and an assessment of each according to the criteria presented previously in this white paper. Each is scored by tractability (T), significance (S), relevance (R), and feasibility (F). A 1 is low, 5 is high, and U is unknown. A brief discussion of the rankings and descriptions of potential analytical approaches are also included for each operational question.

Where do physical proximity of (a) large amounts of irrigated agriculture, (b) scarcity of irrigation water, and (c) low-salinity produced water injected into disposal wells exist?

T=4	S=4	R=3	F=4

Comment: California is the nation's leading agricultural producer, and irrigation poses a demand for water that outstrips every other sector. This question aims to identify and prioritize geographic regions where SDIP produced water may be used to address water scarcity concerns for irrigation from a volume perspective.
Proposed Analytical Approach: Calculate irrigated acreage for crops or pasture and water use for irrigation by county using USDA National Agricultural Statistics Service (NASS) and USGS National Water Use Database. Evaluate water scarcity by groundwater basin using DWR priority water stress designations. For each oil field, calculate produced water volumes that are categorized as SDIP and are injected into the subsurface for disposal. Integrate datasets spatially to visualize overlap and identify priority areas.

What is the relative carbon intensity of treated produced water?

T=3	S=3	R=4	F=3

Comment: The production, transport, and delivery of water often require substantial energy inputs and have associated greenhouse gas emissions. A significant proportion of energy used in the State of California goes toward that movement of water and as such the climate footprint of many water resources are non-negligible (CEC, 2005). Oil production and associated produced water production also require significant energy inputs, especially in the case of thermally enhanced oil recovery (e.g., steam injection), which drives much of the carbon intensity of oils (even more so than refining) (CCST, 2015; Brant and Unnasch, 2010). As such, this question prompts a discussion about climate tradeoffs of produced water treatment to levels acceptable for reuse compared to the reliance on other water resources. Answering this question depends on knowledge of which types of treatment are applied to which volumes of water and where. Unfortunately, as discussed above the data are unsatisfactory in this regard, though broad ranges of estimates may be established with certain assumptions about which categories of treatment are likely to use which processes and materials.
Proposed Analytical Approach: Estimate carbon intensity of produced water using carbon intensity by produced fuel type, determined by CARB. Identify the various treatment categories and calculate volumes from the SB 1281 dataset and then undertake a literature review to estimate the carbon embedded per acre-foot of treated water by each treatment type. Next, undertake a literature review to generate estimates of carbon intensity of other water sources used for similar purposes (e.g., groundwater pumped locally, water imported from the Colorado River, etc.). With these data and estimates, it would be possible to quantitatively compare the carbon intensity of produced water from various production types (hydraulic fracturing, steam injection, water flooding) and the carbon intensity of other water sources.

Are there opportunities for conservation and efficiency by reducing water volumes used, or by using lower-quality and less in-demand sources? How do these vary in space and time?

T=2	S=5	R=5	F=1

Comment: The key question herein is whether freshwater diversions can be reduced or replaced with brackish groundwater or produced water. This question will be best answered with a literature review on techniques for water conservation and efficiency in the oil and gas industry and stakeholder consultations with operators in California, rather than data analysis. The ability to fully answer this question hinges on knowing what quality of water operators require in their operations, as well as the specific composition of water that is injected into disposal wells or placed in percolation pits. Alternatively, the question could be answered more narrowly, examining only where non-produced freshwater is used in oil and gas development and production while produced water is disposed of.
Proposed Analytical Approach: The first step in addressing this question would be to understand what quality of water is required for a particular purpose, which would require interviews and literature review as a start, though it is not clear that operators will necessarily know all relevant parameters, nor whether the literature is clear on the subject. To look at freshwater use, the study can identify locations and volumes where non-produced freshwater is used for oil and gas development purposes while produced water is injected into disposal wells or percolation pits. But the question will remain whether the water sent for disposal is of appropriate quality to replace the non-produced freshwater diversions.

What technology, infrastructure, and economic barriers exist that affect the reuse of produced water?

T=1	S=3	R=4	F=2

Comment: Increased reuse of produced water requires financial, infrastructure, and labor inputs for water transport, treatment, storage, and handling. The ability to meet these requirements depends on the location and scale of expanded reuse, type of reuse method, and associated water quality requirements that are protective of human health and the environment. While answering this question is certainly relevant to produced water reuse, it seems the question on its own lacks a clear nexus with the SB 1281 dataset. As other questions are answered, however, it is likely that various aspects of this topic will be discussed in various contexts, or will figure into background material in the Phase II report.
Proposed Analytical Approach: Literature review to summarize previous techno-economic assessments of large-scale produced water treatment and transport for reuse and discuss findings using calculated volumes of SDIP produced water currently injected for disposal in California (Meng et al., 2016).

Candidate Operational Questions for Phase II

Secondary evaluation question #5, relating to opportunities to improve management of water sources via conservation and produced water reuse, includes one question that may be considered for Phase II analysis:

- *Where do physical proximity of (a) large amounts of irrigated agriculture, (b) scarcity of irrigation water, and (c) low-salinity produced water injected into disposal wells exist?*

The following are highly significant or relevant questions, but are less tractable than those listed above. Some of these may at most be partially addressed in Phase II, but aspects of each may warrant further exploration and discussion, perhaps including detailed research proposals to answer questions with appropriate data:

- *What is the relative carbon intensity of treated produced water?*

- *Are there opportunities for conservation and efficiency by reducing water volumes used, or by using lower-quality and less in-demand sources? How do these vary in space and time?*

The following operational questions, while relevant to the SB 1281 intent, will likely not be addressed in Phase II. Though these are essential questions, they are either not supported by enough data, have or will be answered by other studies, or are not clearly within the scope of the SB 1281 Study, which is focused on testing the SB 1281 database, and therefore must require the database to answer it. Material related to these questions may still be incorporated in background material in the Phase II report.

- *Which technology, infrastructure, and economic barriers exist that affect the reuse of produced water?*

Primary Study Question: *What is the utility of the SB 1281 dataset to answer important questions on water resources, public health, and the environment, and are there opportunities for improvement?*

During Phase II, the study team will evaluate the efficiency, quality, and utility of the SB 1281 dataset through direct assessment of the database and also by working toward answering a subset of the secondary evaluation questions posed in this report. Operational questions that can guide an analysis of this larger question about the SB 1281 dataset include:

Is the dataset designed in a manner that facilitates answering important questions?

Comment: Design of a dataset that provides new and unique information generally requires an evaluation of existing relevant data (including accessibility), a well-defined question(s) the data are meant to address, an understanding of appropriate scales of sampling suitable for the question(s) posed, and a feedback mechanism between the data users and sources to ensure the data types, quantity, and quality fit the scope of investigations. Not only do the way the raw data are collected, recorded, and stored (format and location) matter, but the variables chosen of course determine how useful a set of data may be. To test the suitability of the variables to answer key questions of concern, the questions posed after this section will be candidates to form a basis for a functional evaluation of the dataset, like use cases.
Proposed Analytical Approach: Examine the raw data, reporting forms, reporting instruction/support, submission process, data entry process, data accessibility, and other utility metrics to identify errors, gaps, resolution consistency, and potential points of inaccuracy. Interviews with agency staff and operators will be useful.

Are there sufficient quality control processes in place to ensure the data are accurate and have full coverage?

Comment: This question is straightforward and important; understanding current practices will inform potential suggestions for ensuring high data quality.
Proposed Analytical Approach: Along with the raw data examination outlined above, answering this question would require interviewing data managers at the Division, and operators, as well as examining frameworks for other large dataset quality control practices.

Are the data organized in a manner that facilitates connection with other important public datasets, both by the Division and by other agencies?

Comment: This question will be answered throughout Phase II of the study, as secondary evaluation questions and operational questions requiring multiple datasets are addressed.
Proposed Analytical Approach: Note how formats, data resolution, units, and subjects align while working toward answering secondary evaluation questions.

Would aligning the Division's data stewardship practices with existing multi-agency practices, such as those designed under the California Open and Transparent Water Data Act (AB 1755), significantly improve the utility of the SB 1281 dataset?

Comment: This study comes at a time when California—through Department of Water Resources, in consultation with the California Water Quality Monitoring Council, the State Water Resources Control Board, and the California Department of Fish and Wildlife—is working to create, operate, and maintain a statewide integrated water data platform; and to develop protocols for data sharing, documentation, quality control, public access, and promotion of open-source platforms and decision support tools related to water data (CALI, 2016). These multi-agency efforts to satisfy the Open and Transparent Water Data Act (AB 1755, Dodd) are yielding data stewardship practices that may be useful for the Division moving forward with the SB 1281 (and other) datasets.
Proposed Analytical Approach: Comparisons can be made between the data stewardship practices associated with this dataset and the frameworks being developed under AB 1755. If the SB 1281 dataset is insufficient to answer a particular question, the specific data issue will be identified (e.g. differentiating between data errors, inappropriate variables or scales for purpose, etc.) From this point, it will be determined whether particular practices from AB 1755 efforts could be applied to prevent such issues.

What data gaps exist within the SB 1281 dataset, and what essential datasets do not currently exist, or are not available?

Comment: This question is among the most important data questions in this document, as it will assist in identifying (a) where expected data are missing (either by design or by reporting) from the SB 1281 dataset, and (b) what necessary data is yet to be collected or made available.
Proposed Analytical Approach: When a question cannot be answered, the specific type of data will be identified that would allow it to be, as well as the ideal format and scale, to the extent feasible.

Where important data are missing, which agencies would be best suited to collect more information?

Comment: With a resource as ubiquitous and vital as water, it is perhaps not surprising that multiple agencies are responsible for regulating various different aspects of that resource. When data are found to be missing (i.e. not collected) or unavailable, it will be important to understand which entity has resources best aligned with filling that gap.
Proposed Analytical Approach: Identify the essential roles of various water-related agencies and match their missions to unanswered questions.

Conclusion

Phase I of the SB 1281 data study has yielded an extensive list of questions that can be considered key to:

a. understanding issues surrounding the sources, use, production, treatment, storage, and reuse of water in oil and gas activities;

b. testing the utility of existing datasets, including the SB 1281 dataset geared toward addressing such issues; and

c. guiding the design of future datasets to eventually fill data gaps identified herein and any others will be identified during Phase II.

By first posing a broad array of key questions, the resulting framework for evaluating the utility of the SB 1281 dataset is not constrained by any limitations of the original design. In providing a preliminary assessment of narrowing which questions could fruitfully be addressed, this white paper has already identified several areas that could be modified to deliver essential data that are not currently available elsewhere. These include operator reporting codes that could be clarified for easier reporting or refined to provide more information on treatment methods and materials, reporting of chemical use or other water quality data beyond TDS, and a reporting of TDS on a finer scale than suitable/not suitable for domestic or irrigation purposes.

The series of questions provided herein does not indicate a scope of work, but questions covering a broad range of topics that the SB 1281 dataset might be expected to address, either independently or in conjunction with other available datasets. The full list of questions in Phase I is broad in its scope and generous in its consideration of relating to the intent of SB 1281. The range of questions has been narrowed through a preliminary and qualitative assessment of each question's tractability, significance, relevance, and feasibility. Based on the initial assessments of data availability and quality, it appears that the following operational questions, organized below under broad secondary evaluation questions, will be the most tractable and feasible candidates for questions to address in Phase II.

What are the sources, volumes, and quality of water used for oil and gas development and production in California?

- *What are the gross water volumes, sources, and qualities used and generated on a per-operator, per-field basis? What are the net volumes of water imported and exported from oil and gas-producing reservoirs? How do these vary in space and time?*

- *What are the water volumes, sources, and qualities used for different oil and gas production methods, e.g. hydraulic fracturing and enhanced oil recovery? How do these vary in space and time?*

What are the characteristics/quality of produced water across the state, and how do these vary over time?

- *What is the salinity of produced water across the state?*

- *What are the sources and volumes of produced water recycled for use in oilfields in the state? On local and regional scales? Compared with other oil-producing states and regions?*

- *What are the sources and volumes of produced water recycled for use in applications beyond the oilfield? How do these quantities compare with other oil-producing states and regions?*

How does treatment impact produced water availability as a potential resource, both within and outside of oilfields?

- *What proportion of produced water is currently treated prior to disposal or any reuse application in California?*

- *Of the quantities of produced water treated, what proportion is sent for disposal? What proportion is reused within the oilfield? What proportion is reused outside of the oilfield?*

- *Which operators or areas of the state reuse the most produced water by volume and proportion?*

- *What applications are currently the largest destinations for treated produced water?*

What are the potential and actual hazards, risks and impacts to environmental and human health from various dispositions of reused water discharges to land, water, and subsurface injection?

- *Where are the locations of these percolation pits geographically with respect to groundwater that is currently used or in the future could be used for drinking, food crop irrigation and other activities with potential human exposure pathways?*

- *What volume of produced water is discharged to water districts for food crop irrigation and livestock watering?*

- *Where, geographically, is produced water sent for reuse in agricultural irrigation?*

- *What volume of produced water is injected into UIC wells annually?*

Are there unrealized opportunities to reduce stress on other water resources, including conservation and efficiency, improving and expanding direct and indirect reuse of produced water?

- *Where do physical proximity of (a) large amounts of irrigated agriculture, (b) scarcity of irrigation water, and (c) low-salinity produced water injected into disposal wells exist?*

Phase II will begin with a more detailed scoping process to narrow this list to a feasible suite of questions to analyze. The steering committee and authors will develop more detailed assessments of the analytical steps, timelines, and resources required to answer these questions in whole or in part, and seek to optimize tradeoffs between research avenues given time and resources available in Phase II, keeping in mind the goal of learning the strengths and limitations of the SB 1281 dataset. This process will be carried out with careful consideration of each question's specific nexus with the data and intent of SB 1281, and the study team's ability to productively address the issue with the current dataset, as well as to present novel data analyses that contribute to a better understanding of these topics.

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Glossary

API number - a unique, permanent, numeric identifier assigned to each well drilled for oil and gas in the United States; API number is an industry standard established by the American Petroleum Institute.

CAS number - unique numerical identifier assigned by the Chemical Abstracts Service (CAS) to every chemical substance described in the open scientific literature

Hydraulic fracturing – more commonly known as fracking or fracing, this is a well stimulation technology in which fluids and proppants are injected under pressure to crack the oil-bearing formation to increase the rate at which oil and gas flow to the well.

Water Suitable for Domestic or Irrigation Purposes – This term was coined in SB 1281, but no technical definition was offered in the statute. For the purposes of SB 1281 reporting, the State Water Board recommended that the Division use a threshold of water under 10,000 mg/L TDS.[1] In this report, we use the term Suitable for Domestic or Irrigation Purposes (SDIP) as synonymous with water that is <10,000 mg/L TDS. The term is used for consistency with the Division data reporting and is not intended to imply a scientific or value judgment that this threshold is a precise or accurate delineation of which water is suitable for household or agricultural uses.

Water Use Intensity –Water used per unit of oil or natural gas produced.

Well Stimulation – an umbrella term encompassing acid stimulations, acid fracturing, and hydraulic fracturing.

1. August 19, 2015 Letter from the State Water Resources Control Board to the Division of Oil, Gas, and Geothermal Resources defining SDIP for the purpose of reporting under PRC §3227. Accessed at: ftp://ftp.consrv.ca.gov/pub/oil/SB1281/Letter_From_SWRCB_Defining_Water_Quality_for_SB_1281_2015-08-19.pdf

Appendix I

Regulation of SB 1281

With the intent to make information on water use, production, storage, treatment and recycling more transparent to the public, SB 1281 requires the information collected by the Oil and Gas Supervisor to be reported on a quarterly basis. SB 1281 also requires the Division to use a standardized form or format to facilitate reporting, and to use non-custom software, as feasible, to implement online reporting from operators. In response to this mandate, the Division has developed a Microsoft Excel form for oil and gas operator quarterly use, and will transition to an online platform, WellSTAR 2.0 in late 2018 as part of its efforts to modernize its data management systems.[1]

In the interim, operators are provided quarterly with pre-populated water report forms that are emailed directly from the Division, and due within one month of the end of the quarter.[2] The form is a Microsoft Excel spreadsheet with protected, pre-populated operator-specific data on multiple tabs. Each tab represents a specific form:

- Form 110Q - Quarterly Water Production Report.
- Form 110BQ - Quarterly Water Injection Report.
- Form 110EQ - Quarterly Well Allocation List - A listing of production wells, used to allocate injected volumes of produced water in injection wells, located in the same field.
- Form 110FQ - Quarterly Other Water Allocation - Report by oil field on the source and intended use of water in storage or used for non-injection well purposes.

The data codes for these forms are provided in Tables 4-7 to illustrate the range of categories operators may choose from to describe their water source, use, disposition, and treatment.

To accommodate the provision in SB 1281 that monthly statements to the Supervisor include water information beyond production and injection, the statement forms have been updated to include more fields to align with the quarterly reports. Data collected for the purposes of satisfying SB 1281 are included in monthly production and injection databases.

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1. California Department of Conservation, Division of Oil, Gas, and Geothermal Resources. 2017. *Renewal Plan: New 2017 Update: To Usher in a New Era of Oil and Gas Regulation*. ftp://ftp.consrv.ca.gov/pub/oil/Publications/renewal-plan2017-lrg.pdf

2. Operator Requirements for Water Reporting. Quarterly Water Report Forms. http://www.conservation.ca.gov/dog/SB%201281/Pages/OperatorRequirements.aspx

Table 4. Water Disposition Codes

WATER DISPOSITION CODES for 110Q		
01	Sump (unlined) - Evaporation and Percolation (infiltration)	Water is placed into an unlined sump, allowed to percolate into the ground and/or evaporate into the atmosphere.
02	Sump (lined) - Evaporation	Water is placed into a lined sump, open tank, or similar container for evaporation into the atmosphere.
03	Surface Water Discharge - Ocean, Lake, Pond, River, Creek, Aqueduct, etc…	Water is discharged into a surface body of water such as an ocean, lake, pond, river, creek, aqueduct, canal, stream, or watercourse.
04	Domestic Sewer System	Water is placed into a sewage disposal or treatment system, which is generally operated by a municipality or consortium for domestic waste.
05	Subsurface Injection - In oil field by operator - Class II wells (complete Well Allocation List tab)	Water is injected into the subsurface of the same oil field and operator, from which it was produced. Please complete the Well Allocation List table. (Note: the volume attributed for each well for this disposition type on form 110Q, should match the sum for each well on the Well Allocation List form.)
06	Other - Commercial disposal, Industrial use, non-class II well, etc…	Water is disposed of by another method, such as commercial disposal, industrial use, non-class II wells, etc…
07	Sale/Transfer - To other operator or oil field	Water is sold or transferred to another operator or oil field.
08	Surface Discharge - Land (dust control, landscaping, etc…)	Water is used on oil field land or surface for dust control, landscaping, pasture augmentation, infiltration, evaporation, etc…
09	Operator's facilities within oil field (i.e., tankage, onsite storage, equipment/facility cleaning & testing, etc…)	Water is used for operator's facilities within the oil field (i.e., tankage, equipment operation, onsite storage, equipment/facilities cleaning and testing, etc…)
10	Well Stimulation Treatment	Water is used in a well stimulation treatment operation (i.e., hydraulic fracturing, acid matrix, acid fracturing, etc…)
11	Sale/Transfer - Domestic Use - (agriculture, water replenishment, livestock, etc…)	Water is used for agriculture, irrigation, water replenishment, water banking, livestock, etc..
12	Drilling, well work, and well abandonment operations	Water is used to support well drilling, rework, and abandonment operations, for such things as well control fluid, drilling mud, cementing, etc ...

Table 5. Water Source Codes

WATER SOURCE CODES for 110BQ & 110FQ	
Oil or gas well produced - In oil field by operator	Produced from an oil or gas well, and used within the same field by the same operator from which it was produced.
Water source well - In oil field by operator	Produced from a water source well, and used within the same field by the same operator from which it was produced.
Domestic Water System - Fresh water	Obtained from domestic fresh water system (water district, municipality, public or private entity) where the water is primarily intended for residential or commercial use.
Surface Water - Ocean, Lake, Pond, River, Creek, Aqueduct, etc…	Extracted from a surface water body such as an ocean, lake, pond, river, creek, aqueduct, canal, stream, or watercourse.
Industrial Waste - Class II fluid treated by 3rd party	Class II fluid obtained for disposal in a commercial class II well.
Domestic Waste Water Treatment Facility - Recycled water	Obtained as recycled water from a domestic waste water treatment facility
Other - Specify source (All fluid in non-class II wells monitored by the Division, or other class II fluids not defined)	This category is used for tracking all non-class II fluid used in EPA wells, and monitored by the Division. This category is also used for all other class II fluid not covered by the defined water source categories. When such is the case, the source of the fluid must be specified (i.e. XYZ refinery waste, John's Automotive Service waste pit reclaimation ...).
Oil or gas well produced - Transferred or purchased from other operator or oil field	Obtained as a purchase/transfer from a produced oil or gas well from another operator or oil field. This is not to be used for commercial class II wells.
Well Stimulation Treatment - Recycled fluid	Produced as flowback fluids after the completion of a well stimulation treatment operation (i.e., hydraulic fracturing, acid matrix, acid fracturing, etc…)
Other class II Recycled fluid source - In oil field by operator (i.e., tankage, onsite storage, sumps, cellars, spillage-cleanup…)	In oil field by Operator (i.e., tankage, onsite storage, sumps, cellars, spillage-cleanup…)
Recycled class II fluids from operator's drilling, well work, and well abandonment operations	Class II fluid recycled from operator's drilling, rework, and abandonment operations, including recovered well control fluid, well cleanup and displacement fluids, etc…

Table 6. Type of Water/Disposal Recipient Codes

TYPE OF WATER SOURCE/DISPOSAL RECIPIENT CODES for 110Q, 110BQ & 110FQ	
Ocean	Name of the Ocean
Lake	Name of the Lake
Pond	Name of the Pond
River	Name of the River
Creek	Name of the Creek
Aqueduct	Name of the Aqueduct
Canal	Name of the Canal
Stream	Name of the Stream
Watercourse	Name of the Watercourse

Table 7. Intended Use Codes

INTENDED USE CODES for 110FQ	
Sump (unlined) - Evaporation and Percolation (infiltration)	Water to be placed into an unlined sump, allowed to percolate into the ground and/or evaporate into the atmosphere.
Sump (lined) - Evaporation	Water to be placed into a lined sump, open tank, or similar container for evaporation into the atmosphere.
Surface Water Discharge - Ocean, Lake, Pond, River, Creek, Aqueduct, etc…	Water to be discharged into a surface body of water such as an ocean, lake, pond, river, creek, aqueduct, canal, stream, or watercourse.
Domestic Sewer System	Water to be placed into a sewage disposal or treatment system, which is generally operated by a municipality or consortium for domestic waste.
Subsurface Injection - In oil field by operator - Class II wells	Water to be injected into the subsurface of the same oil field and operator from which it was produced.
Other - Commercial disposal, Industrial use, non-class II well, etc…	Water to be disposed of by another method, such as commercial disposal, industrial use, non-class II wells, etc…
Sale/Transfer - To other operator or oil field	Water to be sold or transferred to another operator or oil field.
Surface Discharge - Land (dust control, landscaping, etc…)	Water to be used on oil field land or surface for dust control, landscaping, pasture augmentation, infiltration, evaporation, etc…

Appendix II

Select Databases and Relevant Secondary Evaluation Questions

Below is a selection of publicly available databases that can inform aspects of the five secondary evaluation questions (SQ #1-5). For each database, a description of variables and how they can be used according to each SQ is listed.

Dataset	Variables included	(SQ #) Relevance
SB 1281 Data and Reports	API number, water volume produced, operator, field, reporting period, date reported, prepared by, pool well type, source of water, suitable for domestic or irrigation purposes	(SQ 1) To determine water volumes, sources, and quality (i.e. TDS) of water used per operator, per field, or by production methods and variability over time.
SB 1281 Data and Reports	API number, field, SDI, date reported, reporting period, water disposition, water volume produced, source of water	(SQ 2) To determine salinity (<10,000ppm TDS is considered suitable for domestic or irrigation use) and sources and volumes of produced water recycled for use in oilfields and other applications
SB 1281 Data and Reports	Water volume produced, treated (Y/N), treatment method, disposition	(SQ 3) To determine produced water treatment methods for different disposal or reuse categories in California
SB 1281 Data and Reports	API number, pool well type, field, water volume produced, water volume injected, disposition	(SQ 4) To determine locations of and quantify water injected for UIC and other disposal or reuse methods
SB 1281 Datasets	API number, Suitable for domestic or irrigation purposes	(SQ 5) Produced water volumes with TDS <10,000 ppm; API can be used to determine location
CA Stimulation Events (SB 4)	Chemical name, CASRN	(SQ 2, SQ 4) To characterize chemical use in well stimulation events (2014 to present)
CA Water Conservation Reporting	Monthly potable water production by supplier, recycled water (optional reporting)	(SQ 1) To calculate proportion of local water production used for oil and gas production
CA Water System Service Areas	Water system, county served, district, population count, service connections	(SQ 4) To identify areas and populations served by various water systems across CA
CA Water Wells	Location, depth, well type	(SQ 4) To identify location and depth of existing and proposed water wells statewide

Dataset	Variables included	(SQ #) Relevance
Cal OES Spills Database	Spill substance and quantity, not limited to oil and gas	(SQ 4) To determine type and amount of spilled waste related to oil and gas
CARB Carbon Intensity Lookup	Fuel type, pathway description, emissions (direct/indirect/total)	(SQ 3, SQ 5) To determine carbon intensity of produced water by region of production
Chemical Use – Reuse Permits (13267 orders)	Chemical name, CASRN, volume, date/frequency of use	(SQ 3) To identify chemicals used in oil and gas operations associated with produced water reused for agricultural irrigation
Chemical Use- Reuse Permits (13267 orders)	Chemical name, CASRN, volume, date/frequency of use	(SQ 2, SQ 4) To identify chemicals used in oil and gas operations associated with produced water reused for agricultural irrigation
The Division Oil and Gas Production	API number, oil and gas produced, # of days producing per month	(SQ 1) To assess produced water production per unit of oil and gas produced across different production methods
Food Safety Expert Panel Materials	VOCs, SVOCs, TPH	(SQ 3) To determine irrigation water quality from monitoring efforts
FracFocus	Chemical name, CASRN, date, API number, well type	(SQ 2, SQ 4) To characterize chemical use in well stimulation events nationally
Gans et al. 2018; Kulongoski et al. 2016; Davis et al. 2014	API number, lat/long, TDS, major ions, DOC, etc.	(SQ 2) To characterize produced water quality in California
Regional Water Board Adopted Orders	TDS, chemical additives (no CASRN), method, reporting limit	(SQ 2, SQ 3, SQ 4) To characterize produced water quality in California using monitoring data from waste discharge permits and other documents
Reused Oilfield Produced Water Chemistry (AB 1328)	Chemical name, CASRN	(SQ 2, SQ 4) To identify trade secret or proprietary chemicals used in oil and gas operations associated with produced water reused for agricultural irrigation
South Coast Stimulation Events (SCAQMD 1148.2)	Chemical name, CASRN, total mass (pounds)	(SQ 2, SQ 4) To characterize chemical use during South Coast routine operations and stimulation events (2013 to present)
Tidwell and Moreland (2016)	Water consumption for energy production by country, per capita, per dollar GDP	(SQ 1) To assess water consumption for various forms of energy production internationally
USDA National Agricultural Statistics Service	Irrigated acreage by crop and by county	(SQ 5) To determine irrigated acreage by county

Dataset	Variables included	(SQ #) Relevance
USGS National Water Use Information	Total groundwater and surface water (fresh and saline), total withdrawals, public supply, self-supplied domestic, livestock, irrigation, self-supplied industrial (gallons/day)	(SQ 1, SQ 5) To assess water usage by county and water use category (1950 – 2010)
USGS Produced Water Database	Lat/long, TDS, well type, metals, BTEX	(SQ 2) To characterize produced water quality in California and other oil-producing states
Waste Disposal Ponds - 2015	Source, field, operator, lease, lat/long, county, status, number of ponds, DOGGR District, WQ District	(SQ 4) To determine percolation pit locations (as of April 2015)
Waste Disposal Ponds - 2018	Global ID, # of permitted ponds, # of unpermitted ponds, enforcement actions, status	(SQ 4) To determine percolation pit locations (2016 – 2018)

Appendix III

Language of SB 1281

Senate Bill No. 1281

CHAPTER 561

An act to amend Section 3227 of, and to add Section 3226.3 to, the Public Resources Code, relating to oil and gas.

[Approved by Governor September 25, 2014. Filed with Secretary of State September 25, 2014.]

LEGISLATIVE COUNSEL'S DIGEST

SB 1281, Pavley. Oil and gas production: water use: reporting.

Under existing law, the Division of Oil, Gas, and Geothermal Resources in the Department of Conservation regulates the drilling, operation, maintenance, stimulation, and abandonment of oil and gas wells in the state. Existing law requires the owner of any well to file with the State Oil and Gas Supervisor a monthly statement that provides certain information relating to the well, including what disposition was made of the water produced from each field. Existing law provides that a person who fails to comply with specific laws relating to the regulation of oil or gas operations, including failing to furnish a report or record, is guilty of a misdemeanor.

This bill would require the statement to the supervisor to include the source and volume of any water reported, including water used to generate or make up the composition of any injected fluid or gas, as provided, and would require that information to be reported on a quarterly basis. The bill would also require the statement to include additional information, including the treatment of water and the use of treated or recycled water in oil and gas field activities, as provided, and would require that information to be reported on a quarterly basis. The bill would require the division, among other things, to use a standardized form or format to facilitate reporting and to use noncustom software, as feasible, to implement online reporting by the operator of specified information. Because a violation of the bill's reporting requirements by an owner or operator would be a crime, the bill would impose a state-mandated local program.

The California Constitution requires the state to reimburse local agencies and school districts for certain costs mandated by the state. Statutory provisions establish procedures for making that reimbursement.

This bill would provide that no reimbursement is required by this act for a specified reason.

DIGEST KEY

Vote: majority   Appropriation: no   Fiscal Committee: yes   Local Program: yes

BILL TEXT

THE PEOPLE OF THE STATE OF CALIFORNIA

DO ENACT AS FOLLOWS:

SECTION 1.

Section 3226.3 is added to the Public Resources Code, to read:

3226.3.

The division shall annually provide to the State Water Resources Control Board and the California regional water quality control boards an inventory of all unlined oil and gas field sumps.

SEC. 2.

Section 3227 of the Public Resources Code is amended to read:

3227.

(a) The owner of any well shall file with the supervisor, on or before the last day of each month, for the last preceding calendar month, a statement, in the form designated by the supervisor, showing all of the following:

(1) The amount of oil and gas produced from each well during the period indicated, together with the gravity of the oil, the amount of water produced from each well, estimated in accordance with methods approved by the supervisor, and the number of days during which fluid was produced from each well.

(2) The number of wells drilling, producing, injecting, or idle, that are owned or operated by the person.

(3) What disposition was made of the gas produced from each field, including the names of persons, if any, to whom the gas was delivered, and any other information regarding the gas and its disposition that the supervisor may require.

(4) What disposition was made of water produced from each field and the amount of fluid or gas injected into each well used for enhanced recovery, underground storage of hydrocarbons, or wastewater disposal, and any other information regarding those wells that the supervisor may require.

(5) The source of water, and volume of any water, reported in paragraph (4), including the water used to generate or make up the composition of any injected fluid or gas. Water volumes shall be reported by water source if more than one water source is used. The volume of untreated water suitable for domestic or irrigation purposes shall be reported. Commingled water shall be proportionally assigned to individual wells, as appropriate.

(6) The treatment of water and the use of treated or recycled water in oil and gas field activities, including, but not limited to, exploration, development, and production.

(7)

(A) The specific disposition of all water used in or generated by oil and gas field activities, including water produced from each well reported pursuant to paragraph (1). Water volumes shall be reported by disposition method if more than one disposition method is used. Commingled water shall be proportionally assigned to individual wells, as appropriate.

(B) This information shall also include the temporary onsite storage of water, as or if appropriate, and the ultimate specific use, disposal method or method of recycling, or reuse of this water.

(b) Any operator that produces oil by the application of mining or other unconventional techniques shall file a report with the supervisor, on or before March 1 of each year, showing the amount of oil produced by those techniques in the preceding calendar year.

(c)

(1) Upon request and making a satisfactory showing therefor, a longer filing period may be established by the supervisor for any particular owner or operator.

(2) Notwithstanding subdivision (a), the owner of any well shall file with the supervisor, on a quarterly basis, a statement containing the information required to be reported pursuant to paragraphs (5), (6), and (7) of subdivision (a) in the form designated by the supervisor.

(d) The division shall use a standardized form or format to facilitate reporting required pursuant to this section.

(e) The division shall use noncustom software, as feasible, to implement online reporting by the operator of the information required pursuant to paragraphs (5), (6), and (7) of subdivision (a). This information may be reported separately from other information required to be reported pursuant to this section.

(f) For purposes of this section, the following terms have the following meanings:

(1) “Source of water” or “water source” means any of the following:

(A) The well or wells, if commingled, from which the water was produced or extracted.

(B) The water supplier, if purchased or obtained from a supplier.

(C) The point of diversion of surface water.

(2) “Specific disposition of all water” means the identification of the ultimate specific use, disposal method or method of recycling, or reuse of the water. This includes, but is not limited to, the identification of any treatment or recycling method used, injection of the water into specific injection or disposal well or wells, if commingled, discharge of the water to surface water or sumps, and sale or transfer of the water to a named entity.

SEC. 3.

No reimbursement is required by this act pursuant to Section 6 of Article XIII B of the California Constitution because the only costs that may be incurred by a local agency or school district will be incurred because this act creates a new crime or infraction, eliminates a crime or infraction, or changes the penalty for a crime or infraction, within the meaning of Section 17556 of the Government Code, or changes the definition of a crime within the meaning of Section 6 of Article XIII B of the California Constitution.

Appendix IV

CCST Steering Committee Members, Report Authors, and Oversight Committee

Full *curricula vitae* for the Steering Committee members and Authors are available upon request. Please contact the California Council on Science and Technology (916) 492-0996.

Steering Committee Members:

The Steering Committee oversees the report authors and reviews all report content, providing direction for the report.

- **Mike Kavanaugh,** Geosyntec Consultants, Inc. (Chair)
- **Nicole Deziel,** Yale School of Public Health
- **Eric M.V. Hoek,** University of California Los Angeles
- **Susan Hubbard,** Lawrence Berkeley National Laboratory and UC Berkeley
- **James McCall,** National Renewable Energy Laboratory
- **Steve Weisberg,** Southern California Coastal Water Research Project Authority

Report Authors:

- **Brie Lindsey,** California Council on Science and Technology (Phase I Lead Author)
- **Laura Feinstein,** Pacific Institute
- **Seth B.C. Shonkoff,** PSE Healthy Energy, University of California, Berkeley, Lawrence Berkeley National Laboratory
- **Lee Ann Hill,** PSE Healthy Energy

Oversight Committee:

- **Richard C. Flagan,** California Institute of Technology, CCST Board Member
- **Samuel J. Traina,** University of California Merced, CCST Board Member (Joined March 2018)
- **Robert F. Sawyer,** University of California, Berkeley, External Member

Steering Committee Members

Mike Kavanaugh, PhD, P.E., NAE

Senior Principal
Geosyntec Consultants, Inc.

Mike Kavanaugh is a chemical and environmental engineer with more than four decades of consulting experience in a number of technical areas. Mike's professional practice started in the areas of municipal and industrial wastewater treatment, water quality management, and water reuse and drinking water treatment. He expanded his practice to include contaminated groundwater studies, particularly CERCLA-driven remedial investigations/feasibility studies (RI/FS), groundwater remediation, waste minimization and pollution prevention studies, pioneering technology development, as well as third-party peer review and strategic consulting on environmental management and compliance issues. He has also provided technology evaluations including patent reviews of environmental technologies.

As a testifying expert and a fact witness on engineering and hydrogeologic issues related to hazardous waste sites as well as on other issues related to his areas of expertise, Mike has been tapped more than 60 times by attorneys, arbitrators, judges, and government agencies to serve. He also has participated on several mediation and arbitration panels as a neutral technical expert as well as serving as an individual facilitator, mediator, arbitrator, court appointed expert, or "blue ribbon" expert panelist working on project-specific and policy-level issues.

To advance the state of the practice, Mike has contributed to over 80 technical publications and more than 150 presentations to audiences that included congressional and state committees. Currently, he is an instructor for the Princeton Groundwater Course and a consulting professor in the Stanford University Civil and Environmental Engineering Department. He also served on the Board of Directors for the Environmental Law Institute and was the chair of the National Research Council's Committee on Future Options for the Nation's Contaminated Groundwater Remediation Efforts. He was elected into the National Academy of Engineering in 1998.

Susan Hubbard, PhD

Associate Laboratory Director & Senior Scientist, LBNL
Adjunct Professor, Environmental Science, Policy and Management,
University of California, Berkeley

As the Associate Lab Director for Earth & Environmental Sciences Area at Berkeley Laboratory, Dr. Susan Hubbard leads a premier group of ~500 staff that has a significant research portfolio in climate science, terrestrial ecosystem science, environmental and biological system science, fundamental geoscience, and subsurface energy resources. Research within this Area of Berkeley Lab is tackling some of the most pressing environmental and subsurface energy challenges of the 21st Century. Dr. Hubbard is also an Adjunct Professor at UC Berkeley in the Department of Environmental Science, Policy and Management. Dr. Hubbard earned her PhD in Civil and Environmental Engineering at UC Berkeley, and prior to joining Berkeley Lab, she was a geologist at the US Geological Survey and a geophysicist in industry.

As a Senior Scientist at Berkeley Laboratory, Dr. Hubbard's research focuses on quantifying how terrestrial environments function, with a particular emphasis on the development of geophysical approaches to provide new insights about processes relevant to contaminant remediation, carbon cycling, water resources, and subsurface energy systems. She has been honored by the scientific community with several awards, including as an: American Geophysical Union (AGU) Fellow, Geological Society of America (AGU) Felow, receipent of the Society of Exploration Geophysicists (SEG) Frank Frischknecht Award for leadership and innovation in near-surface geophysics, the Birdsall Dreiss Distinguished Lecturer Award, Distinguished Alumni of UC Berkeley, and the SEG Harold Mooney Award for Near Surface Geophysics. Dr. Hubbard has served widely on many scientific boards and has served on the editorial boards of JGR-Biosciences, Water Resources Research, Vadose Zone Journal and the Journal of Hydrology.

Eric M.V. Hoek, PhD

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Eric Hoek is an internationally recognized expert in water treatment, UCLA environmental engineering professor, founder of 4 successful water technology startups, and considered a thought leader in the water industry. He has worked on various aspects of water treatment including drinking water treatment, wastewater treatment, desalination, oil & gas produced water treatment, municipal and industrial water reuse and oil spill remediation. He has served as a consultant to municipal water authorities, water technology startups, hedge funds, venture capital funds, law firms, private research foundations, non-profit foundations, US federal, state and local agencies and foreign national research agencies. He has over 130 scientific publications, over 70 patents filed in the U.S. and internationally, and serves as the Editor-in-Chief of the Nature Publishing Group journal npj Clean Water. He is a graduate of Penn State (B.S.), UCLA (M.S.), Yale University (Ph.D.) and the Executive Management program at the UCLA Anderson School of Management.

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Distributed Energy and Environment Analyst,
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James joined the Systems Modeling & Geospatial Data Science Group in the Strategic Energy Analysis Center in 2015. His interests include techno-economic analyses for various renewable technologies, economic and employment impacts, and systems analysis associated with the energy-water-food-nexus. Prior work experience was as a researcher at a utility law think tank at ASU and a project manager/facilities engineer for an upstream oil and gas producer.

Steve Weisberg, PhD

Executive Director,
Southern California Coastal Water Research Project Authority (SCCWRP)

Dr. Stephen Weisberg is Executive Director of the Southern California Coastal Water Research Project Authority, a research consortium formed by 14 leading water quality agencies in California to ensure a solid scientific foundation for their management activities. Dr. Weisberg's research emphasis is in developing tools to support implementation of, and data interpretation from, environmental monitoring programs. Beyond his research activities, Dr. Weisberg focuses on linking the needs of the management community with science. He serves on numerous advisory committees, including the State of California's Clean Beach Task Force, the California Ocean Protection Council Science Advisory Team, the California Sea Grant Program Advisory Council, and the California Water Quality Monitoring Council. Dr. Weisberg received his undergraduate degree from the University of Michigan and his Ph.D. from the University of Delaware.

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Dr. Brie Lindsey has a research background in oceanography, quantitative biology, and ecology. She is a Senior Program Associate at the California Council on Science and Technology, where she manages a diverse portfolio of projects. She previously served as a CCST Science and Technology Policy Fellow with the Senate Office of Research. Brie holds a PhD in Oceanography from the College of Oceanic and Atmospheric Sciences at Oregon State University and BA in Environmental Sciences from University of California at Berkeley.

Laura Feinstein, PhD

Senior Research Associate,
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Laura Feinstein joined the Water Program at the Pacific Institute in 2016. Laura conducts research on aquatic ecosystems; the impacts of climate change on water resources; the water-energy nexus; and environmental health and justice.

Prior to joining the Pacific Institute, she was a research scientist and project manager with the California Council on Science and Technology. She also served as a Science and Technology Policy Fellow with the California Senate Committee on Environmental Quality and was a California SeaGrant Delta Science Fellow. Laura holds a Ph.D. in Ecology from the University of California, Davis.

Seth B.C. Shonkoff, PhD, MPH

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Lee Ann Hill, MPH

Associate, Environmental Health Program
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Lee Ann Hill joined PSE Healthy Energy in 2016 as part of the Environmental Health Program. Lee Ann has worked in academic, advocacy, industry, and government settings on topics related to energy, material safety, and public health. Her research has focused on environmental and human health impacts of oil and gas and chemical fate and transport.

Lee Ann received her Master's in Public Health from University of California, Berkeley with a concentration in Environmental Health Sciences. She also holds her Bachelor's in Environmental Science from Ithaca College with a concentration in Pollution Science: Local and Global Perspectives.

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